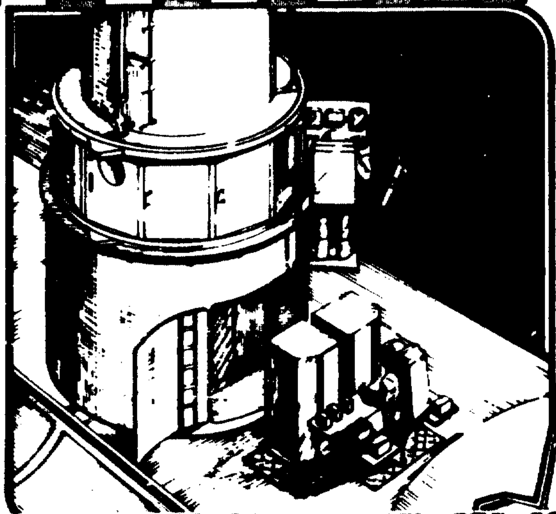
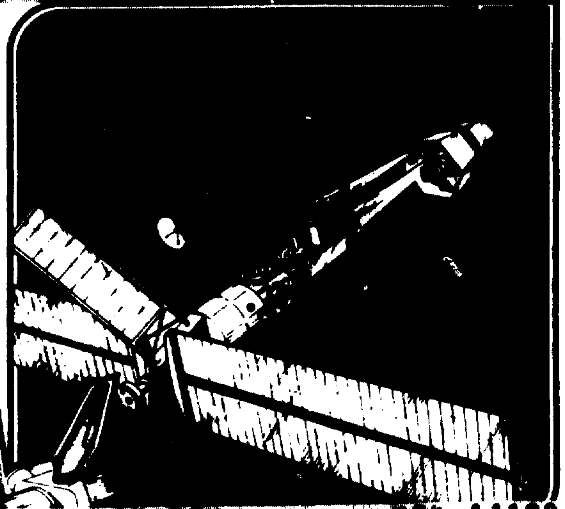
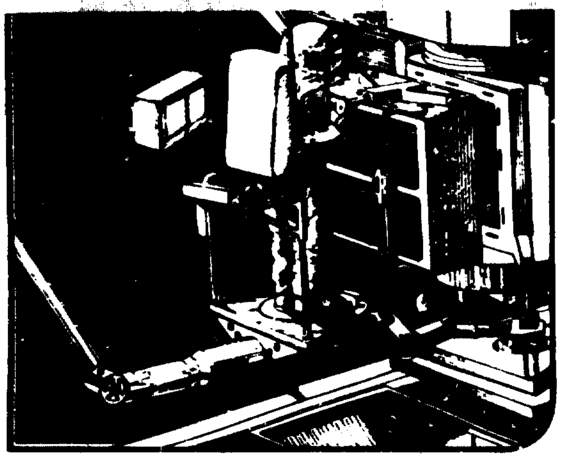
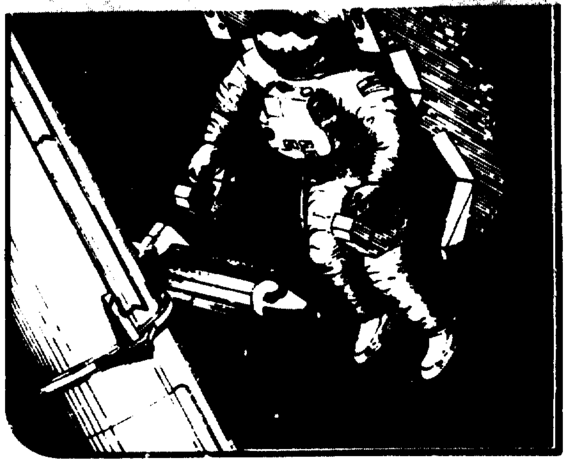
LMSC D798873A





(NASA-CR-171718) SATELLITE SERVICES SYSTEM ANALYSIS STUDY, PART 3 Final Report (Lockheed Missiles and Space Co.) 78 p HC A05/MF A01 CSCL 22A N84-11188 Unclas G3/12 44526





ORIGINAL PAGE IS OF POOR QUALITY

SATELLITE SERVICES SYSTEM ANALYSIS STUDY

PART III FINAL REPORT

CONTRACT NAS 9-16121

DRL ITEM NO. MA-745T
LINE NO. 4

MAR 1982

CR-171718

NASA JOHNSON SPACE CENTER

Lockheed

Lockheed

SATELLITE SERVICES SYSTEM ANALYSIS STUDY

FINAL REPORT
PART III

PRESENTED BY
LOCKHEED MISSILES & SPACE COMPANY, INC.
SUNNYVALE, CALIFORNIA

FOR

JOHNSON SPACE CENTER
HOUSTON, TEXAS

CONTRACT NAS 9-16121
MARCH 1982

SATELLITE SERVICES SYSTEM ANALYSIS STUDY
PART III
FINAL REPORT

- ECONOMIC BENEFIT ANALYSIS
- ADVANCED EXTRAVEHICULAR MANEUVERING UNIT

NASA

Lockheed

Life Support Systems Inc.

SATELLITE SERVICE SYSTEM ANALYSIS STUDY
ECONOMIC BENEFIT ANALYSIS

- BACKGROUND
- GROUND RULES AND ASSUMPTIONS
- INDIVIDUAL DRM RESULTS
- TOTAL USER BENEFIT PROJECTION

NASA Lockheed

GLOSSARY OF TERMS

CAF	Cost Avoidance Factor
CER	Cost Estimating Relationship
COMPLAT	Communications Platform
DoD	Department of Defense
DRM	Design Reference Mission
ELV	Expendable Launch Vehicle
GEO	Geosynchronous
GPS	Global Positioning System
LEO	Low Earth Orbit
LMSC	Lockheed Missiles & Space Company, Inc.
MTBF	Meantime Before Failure
O&M	Operations and Maintenance
ORU	Orbit Replaceable Unit
OTV	Orbit Transfer Vehicle
S&R	Service and Refurbish
SOC	Space Operations Center
ST	Space Telescope
STS	Space Transportation System
Synch Eq	Synchronous Equatorial

SATELLITE SERVICE SYSTEM ANALYSIS STUDY
ECONOMIC BENEFIT ANALYSIS

- $\boxed{\text{BACKGROUND}}$
- GROUND RULES AND ASSUMPTIONS
- INDIVIDUAL DRM RESULTS
- TOTAL USER BENEFIT PROJECTION

NASA Lockheed

ECONOMIC BENEFIT ANALYSIS TASK

PURPOSE: TO ESTIMATE THE POTENTIAL COST BENEFIT TO THE SPACE USER COMMUNITY OF PERFORMING SATELLITE SERVICING

SCOPE:

- SELECTION OF SPECIAL PURPOSE DESIGN REFERENCE MISSIONS (DRMs)
- DEFINITION OF OPTIONAL SERVICE SCENARIOS TO DRIVE OUT COST DIFFERENTIALS
- ESTIMATION OF COST FOR EACH DRM AND APPLICABLE SCENARIO OPTION
- DEVELOPMENT OF TRAFFIC MODEL FOR MISSIONS REPRESENTATIVE OF THE DRMs
- ACCUMULATE BENEFITS ACCURING TO USERS REPRESENTED BY THE MISSION MODEL

SELECTED DRMs

Three design reference missions were selected to meet the majority of goals and objectives of the cost benefit analysis.

The space telescope is an STS accessible satellite designed for service.

HyPOT is tailored to be representative of DoD missions requireing a constellation of satellites. DoD mission examples that could be designed for return to STS accessible orbits are: Transit, NOAA, and GPS.

The Communications Platform is an example of a GEO mission of sufficient size and value to be potentially worthwhile to service.

SELECTED DRMs

DESIGN REFERENCE MISSION	RATIONALE
SPACE TELESCOPE	STS ACCESSIBLE (LOW ALTITUDE, LOW INCLINATION) ONE-OF-A-KIND NASA MISSION DESIGNED FOR SERVICE EXTENSIVE BACKGROUND DATA
HyPOT	REPRESENTATIVE OF DoD SPACE CONSTELLATIONS MEDIUM ALTITUDE, HIGH INCLINATION RETURN TO RENDEZVOUS FROM STS INACCESSIBLE ORBIT
COMMUNICATIONS PLATFORM	GEOSYNCHRONOUS ORBIT REMOTE REFUELING COMMERCIAL USER SMALL CONSTELLATION

SPACE TELESCOPE REFERENCE DEFINITION

This mission provides a vehicle for estimating the impact of planned on-orbit or ground servicing of a low altitude, low inclination satellite. Although the ST is much larger than the average spacecraft launched into a low altitude orbit, it is a well defined mission.

The planned revisit cycle for on-orbit service and return to earth have been chosen to be five years in order that the results be consistent with the other DRMs. The actual program planned revisit cycle is different and has changed as the program has matured.

SPACE TELESCOPE REFERENCE DEFINITION

- USER – NASA
- QUANTITY – 1
- ON-ORBIT MASS 10,554 kg (23,268 LB)
- PLANNED REVISIT CYCLE – 5 YEARS*
- PLANNED RETURN TO EARTH/REFURBISH CYCLE – 15 YEARS*
- ORBIT
  - 28.5° INCLINATION
  - 320 NM CIRCULAR ALTITUDE

*SELECTED FOR COST COMPARATIVE PURPOSES

HyPOT MISSION DEFINITION

This hypothetical mission is defined to provide a means for exploring the economic benefits of satellite service to a user requiring many satellites over extended periods of time. Several past, proposed, and planned missions have similar characteristics and could be constructed with the necessary propulsion capability to return to an STS accessible orbit for service. The service functions performed in the HyPOT service mission are: deployment, retrieval, earth return, changeout, reconfiguration, and resupply.

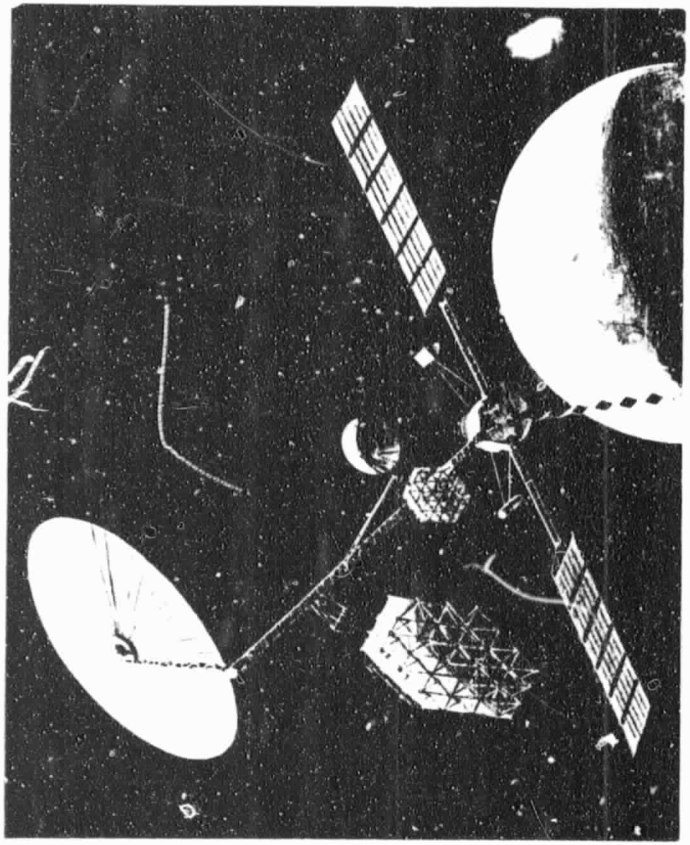
HyPOT MISSION DEFINITION

- USER – DoD
- CONSTELLATION
  - 9 TOTAL (3 EACH IN 3 PLANES)
  - 98.5 DEGREE INCLINATION
  - ORBIT ALTITUDE 450 NM CIRCULAR
- MASS ON-ORBIT 3400 kg (7500LB)
- MISSION DURATION – 15 YEARS
- PLANNED REVISIT CYCLE – 5 YEARS
- OPERATIONAL ORBIT ATTAINMENT FROM LEO
  - SELF CONTAINED TWO-WAY CAPABILITY

COMMUNICATIONS PLATFORM MISSION DEFINITION

This future mission is presumed to be a commercial venture based on multiple large antennas and transponders located in sychronous equatorial orbit. The typical communications satellite is designed for stationkeeping propellants for 7 years. Several early generation COMSATs have outlasted their stationkeeping capability, and have performed a useful function beyond their design life. This indicates that a serviced COMSAT could provide extended capability. The typical constellation is three satellites located approximately 120° apart in longitude. The size of a high-capacity future satellite can well require assembly in orbit. Transfer from LEO to GEO is by OTV.

COMMUNICATIONS PLATFORM MISSION DEFINITION



- USER – COMMERCIAL
- CONSTELLATION
  - 3 (SEPARATE LONGITUDES)
  - 0° INCLINATION
  - SYCHRONOUS ALTITUDE
- MISSION DURATION: 15 YEARS
- PLANNED REVISIT CYCLE: 5 YEARS
- MASS ON-ORBIT 4,540 kg (10,000 LB)
- SERVICE
  - DEPLOYMENT/CHECKOUT
  - REMOTE REFUELING
  - ORU CHANGEOUT

ECONOMIC TRADE OPTIONS CONSIDERED

The cost tradeoff options are identified in this chart. The baseline option against which all satellite service options are compared in the conventional expendable satellite. For satellite servicing to be cost effective, the cost of establishing a space capability and maintaining it over the desired mission duration must be less than the replacement of the satellites at the time of their wearout/failure.

Options II through IV are costed to compare the merits of return to earth for service and in-orbit service from the orbiter and SOC.

ECONOMIC TRADE OPTIONS CONSIDERED

SERVICE OPTION	APPLICATION/DESCRIPTION
I NONE (EXPENDABLE SPACECRAFT)	BASELINE AGAINST WHICH ALL OPTIONS ARE TRADED
II EARTH RETURN–REFURBISH–RELAUNCH	ORBITER IN-BAY RETURN AND RELAUNCH
III ORBITER-BASED ON-ORBIT SERVICE	DEPLOYMENT, OBSERVATION, RETRIEVAL RESUPPLY, REPAIR, CHANGEOUT, RECONFIGURE, ASSEMBLE – FROM ORBITER
IV SOC-BASED ON-ORBIT SERVICE	SAME AS ABOVE FROM SOC (EFFORT LIMITED TO RESOURCES AVAILABLE)

MODELS FOR SOURCES OF COST

RCA PRICE H

- ASSESSES COST TO DEVELOP AND PRODUCE SPACE HARDWARE AGAINST REQUIRED SCHEDULES
- USES A WEIGHT BASED SET OF CERs AS INFRASTRUCTURE, AS WELL AS COMPLEXITY OF DESIGN AND MANUFACTURING
- COMPUTES INTEGRATION COST

RICHARDSON CONSTRUCTION

- COMPUTES COST OF FACILITIES (BUILDINGS, ETC.)
- COMPUTES COST OF SITE PREPARATION
- OPERATES ON DOLLAR PER SQUARE FOOT, CONSTRUCTION DATA BASE

PRICE L

- FROM PRICE H FILE STRUCTURE, COMPUTES COST OF O&M SUPPORT
- ACCEPTS MTBF VALUES, DETAILS OF MAINTENANCE POLICY
- SPARES AS DICTATED BY THE MTBF
- COMPUTES LOGISTICS COST AGAINST SPARES INVENTORY

CER = COST ESTIMATING RELATIONSHIP

ELEMENTS OF COST AND SOURCES

	SOURCE OF COST ESTIMATE
• HARDWARE	
– SATELLITE	RCA "PRICE H"
– ORBIT REPLACEABLE UNITS (ORU)	RCA "PRICE H"
– SERVICE KITS (ASE)	RCA "PRICE H"
– AGE	RCA "PRICE H"
– FACILITIES	RICHARDSON COST MODEL
• SUPPORT	
– GROUND REFURBISHMENT – SATS, ORU, ASE	"PRICE H"
– TRANSPORT – SATS, ORU, ASE, SPECIALIST	COST REIMBURSEMENT GUIDE
– GROUND OPERATIONS	COST REIMBURSEMENT GUIDE
• LOAD/UNLOAD	COST REIMBURSEMENT GUIDE
• SIMULATION AND TRAINING	LMSC
• POCC	COST REIMBURSEMENT GUIDE
• SATELLITE DOWN TIME	'PRICE L'
– SPACE OPERATIONS	
• EVA	COST REIMBURSEMENT GUIDE
• MMU	COST REIMBURSEMENT GUIDE
• SUPPORT VEHICLES	LMSC
• SOC	"PRICE H" + "PRICE L" (JSC)
• STAY TIME	COST REIMBURSEMENT GUIDE

PAGE 14 INTENTIONALLY BLANK

PRECEDING PAGE BLANK NOT FILMED

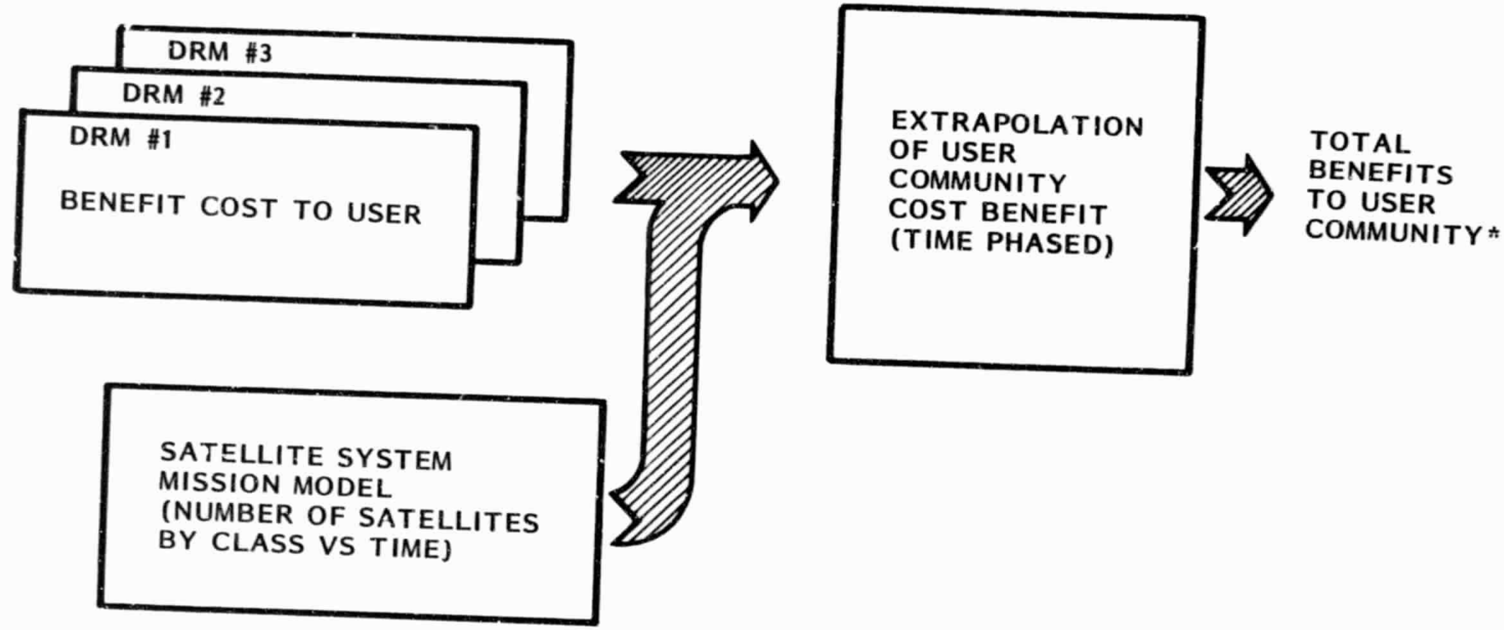
USER COMMUNITY BENEFITS

The DRM options that are carried forward into the benefit analysis were selected from the cost tradeoffs on the basis of lowest mission cost to the user. The differential between the expendable spacecraft and the serviced mission is the user benefit.

A satellite system mission model was defined as a set of space missions of the type represented by the DRMs. The missions that bear little resemblance to the DRM classes were not included in the user benefit analysis.

These inputs are modeled by extrapolation to yield time-phased, economic benefits expected to accrue to the user community. A cumulation routine furnishes the total benefits available to the applicable user community for any selected time frame.

USER COMMUNITY BENEFITS



*1982 REF DOLLARS AND THEN YEAR

SATELLITE SERVICE SYSTEM ANALYSIS STUDY
ECONOMIC BENEFIT ANALYSIS

- BACKGROUND
- $\boxed{\text{GROUND RULES AND ASSUMPTIONS}}$
- INDIVIDUAL DRM RESULTS
- TOTAL USER BENEFIT PROJECTION

NASA Lockheed

GROUND RULES AND ASSUMPTIONS

- THE TIME FRAME OF INTEREST TO THIS ANALYSIS IS 1983 – 2000
  - AVERAGE MISSION DURATION FOR THE USER MISSION MODEL IS 5 YEARS
  - AVERAGE SPACECRAFT MASS IS 2500 kg (5500 LB)
  - COST BENEFITS ARE REALIZED ONLY AT THE END OF THE PLANNED LIFE, i.e., 5 YEARS AFTER LAUNCH
- ALL COSTS ARE COMPUTED IN CONSTANT 1982 DOLLARS
- ALL OPERATIONS COST ARE BASED ON PLANNED OPERATIONS (NO EMERGENCY SERVICE)
- OBSOLESCENCE IS NOT EVALUATED
- NASA SUPPORT SYSTEM DEVELOPMENT COSTS ARE SUNK
  - STS
  - OTV
  - SOC
- BOTH SATELLITE ON-ORBIT SERVICE AND GROUND REFURBISHMENT RETURN THE SPACECRAFT TO ITS INITIAL OPERATING CONDITION WITH ITS ORIGINAL LIFE EXPENTANCY
- STS IS USED TO LAUNCH BOTH EXPENDABLE AND SERVICEABLE SPACECRAFT
- SERVICEABLE SATELLITE DEVELOPMENT COSTS ARE 20 PERCENT GREATER THAN THOSE FOR EXPENDABLE ON THE AVERAGE
- AVERAGE PRODUCTION COST OF THE SERVICEABLE SATELLITE IS 10 PERCENT GREATER THAN FOR THE EXPENDABLE
- ON THE AVERAGE THE COST OF A SHARED STS FLIGHT, e.g., SATELLITE ON-ORBIT SERVICE OR EARTH RETURN IS 1/2 THE DEDICATED COST
- GROUND REFURBISHMENT OF SATELLITES AND ORUs ARE 1/3 THE UNIT PRODUCTION COST
- COST ESTIMATING RELATIONSHIPS ARE BASED ON THE USAF UNMANNED SPACECRAFT COST MODEL V, SEPT 1981
- ESCALATION INDICES USED ARE FROM THE RCA "PRICE" MODEL (NASA CONTROLLER INDICES END AT 1988)

ECONOMIC TRADE OPTIONS

SERVICE OPTION / CANDIDATE DRM	I EXPENDABLE (NO REVISIT)	II EARTH RETURN REFURBISH RELAUNCH	III ORBITER-BASED ON-ORBIT SERVICE	IV SOC-BASED ON-ORBIT SERVICE
SPACE TELESCOPE	●	●	●	
HyPOT	●	●	●	
COMMUNICATIONS PLATFORM	●		●	●

PRECEDING PAGE BLANK NOT FILMED

PAGE 20 INTENTIONALLY BLANK

SPACE TELESCOPE SCENARIOS

Four options were considered for the cost trade-off using the Space Telescope DRM. It could have been an expendable spacecraft launched by expendable boosters. It is actually planned for STS launch, periodic revisit for on-orbit service, and longer term periodic return-to-earth for refurbishment and relaunch.

In order to clearly separate the cost drivers, the options selected for analysis are:

1. Return-to-earth for refurbish and relaunch, Case II
2. On-orbit service, Case IIIA
3. On-orbit service with return at 15 years, Case III

The last simulates one cycle of the planned STS program.

SPACE TELESCOPE SCENARIOS

CASE I – EXPENDABLE

- LAUNCH ST WITH STS
- ST EXPENDED IN 5 YEARS
- REPLACE ST AT 5 YEARS
- REPLACE ST AT 10 YEARS

CASE II – EARTH RETURN, REFURBISH, RELAUNCH

- LAUNCH ST WITH STS
- RETURN ST TO EARTH WITH STS AT 5 YEARS
- RELAUNCH REFURBISHED ST WITH STS
- RETURN ST TO EARTH WITH STS AT 10 YEARS
- RELAUNCH REFURBISHED ST WITH STS
- ST EXPENDED AT 15 YEARS

CASE III – ON-ORBIT SERVICE + RETURN

- LAUNCH ST WITH SPACE TRANS SYSTEM (STS)
- SERVICE ST IN ORBIT WITH STS AT 5 YEARS
- SERVICE ST IN ORBIT WITH STS AT 10 YEARS
- RETURN ST TO EARTH AT 15 YEARS

CASE IIIA – ON-ORBIT SERVICE

- LAUNCH ST WITH STS
- SERVICE ST WITH STS AT 5 YEARS
- SERVICE ST WITH STS AT 10 YEARS
- ST EXPENDED AT 15 YEARS

HyPOT SCENARIOS

Three options were considered for this DRM. The expendable case is the conventional method of establishing a constellation of satellites such as HyPOT. In Case II, the satellites are returned to earth for refurbishment and replaced in groups of three (coplanar satellites) for the on-orbit service case, revisit is performed at five year intervals and the three coplanar satellites are serviced in one STS mission. Three shipsets of ORUs are provided for a single service mission. The rationale is that those returned from the first service mission will be refurbished and made available to the second.

HyPOT SCENARIOS

CASE I – EXPENDABLE

- LAUNCH THREE HyPOTs FOR EACH OF THREE STS FLIGHTS
- HyPOTs HAVE FIVE YEAR LIFE
- LAUNCH NINE MORE HyPOTs AT 5 YEARS
- LAUNCH NINE MORE HyPOTs AT 10 YEARS
- HyPOTs EXPENDED AFTER 5 YEARS

CASE II – EARTH RETURN, REFURBISH, RELAUNCH

- LAUNCH THREE HyPOTs ON EACH OF THREE STS FLIGHTS
- REPLACE NINE HyPOTs AT 5 YEARS USING THREE STS FLIGHTS
  - 1ST REPLACES 3 WITH 3 NEW
  - 2ND REPLACES 3 WITH 3 REFURBISHED FROM FLIGHT NO. 1
  - 3RD REPLACES 3 WITH 3 REFURBISHED FROM FLIGHT NO. 2
- REPEAT REPLACEMENT AT 10 YEARS
- HyPOTs EXPENDED AT 15 YEARS

CASE III

- LAUNCH THREE HyPOTs WITH EACH OF THREE STS FLIGHTS
- SERVICE EACH HyPOT FROM STS AT 5 YEARS
- SERVICE EACH HyPOT FROM STS AT 10 YEARS
- HyPOTs EXPENDED AFTER 15 YEARS

COMPLAT SCENARIOS

Three operational scenarios were selected to define the cost trade-off for this future mission.

Case I, the expendable spacecraft using expendable launch vehicles is the conventional approach to utilizing Synchronous Equatorial orbits. The second option is the application of a reusable OTV which returns to the STS and the ground for refurbishment and reuse. Remote servicing by the OTV is presumed to involve refueling of the Synchronous Equatorial spacecraft and ORU (Orbit Replacable Unit) changeout via robotics.

The third case makes use of the SOC as a base for the OTV which provides capability for refurbishment and refueling without return to earth. The cost estimates in the last case presume that the refueling and servicing of the OTV at the SOC are sunk costs.

COMPLAT SCENARIOS

CASE I – EXPENDABLE

- LAUNCH COMPLAT WITH OTV USING STS
- LAUNCH THREE MORE AT 5 YEARS
- LAUNCH THREE MORE AT 10 YEARS
- OTV EXPENDED AT 10 YEARS
- COMPLAT EXPENDED AT 15 YEARS

CASE III – STS BASED ON-ORBIT SERVICE

- LAUNCH COMPLAT AND OTV USING STS
- OTV PLACES COMPLAT INTO SYNC EQ ORBIT
- OTV RETURNS TO STS
- STS RETURNS OTV TO EARTH
- OTV IS REFURBISHED
- OTV IS REUSED TO LAUNCH COMPLATS NOs. 2 AND 3
- SINGLE OTV SERVICES THREE COMPLATS AT 5 AND 10 YEARS
- OTV RETURNS TO STS
- STS RETURNS OTV TO EARTH FOR REFURBISH, REUSE
- COMPLATS EXPENDED AT 15 YEARS

CASE IV – SOC BASED ON-ORBIT SERVICE

- LAUNCH THREE COMPLATS WITH STS
- SOC HAS OTV AVAILABLE
- OTVs PLACE THREE COMPLATS INTO SYNC EQ ORBIT
- OTV RETURNS TO SOC AFTER EACH USE
- OTV REFURBISHED AT SOC
- SINGLE OTV SERVICES THREE COMPLATS AT 5 AND 10 YEARS
- COMPLAT EXPENDED AT 15 YEARS

SATELLITE SERVICE SYSTEM ANALYSIS STUDY
ECONOMIC BENEFIT ANALYSIS

- BACKGROUND
- GROUND RULES AND ASSUMPTIONS
- $\boxed{\text{INDIVIDUAL DRM RESULTS}}$
- TOTAL USER BENEFIT PROJECTION

NASA Lockheed

SPACE TELESCOPE COST ESTIMATE

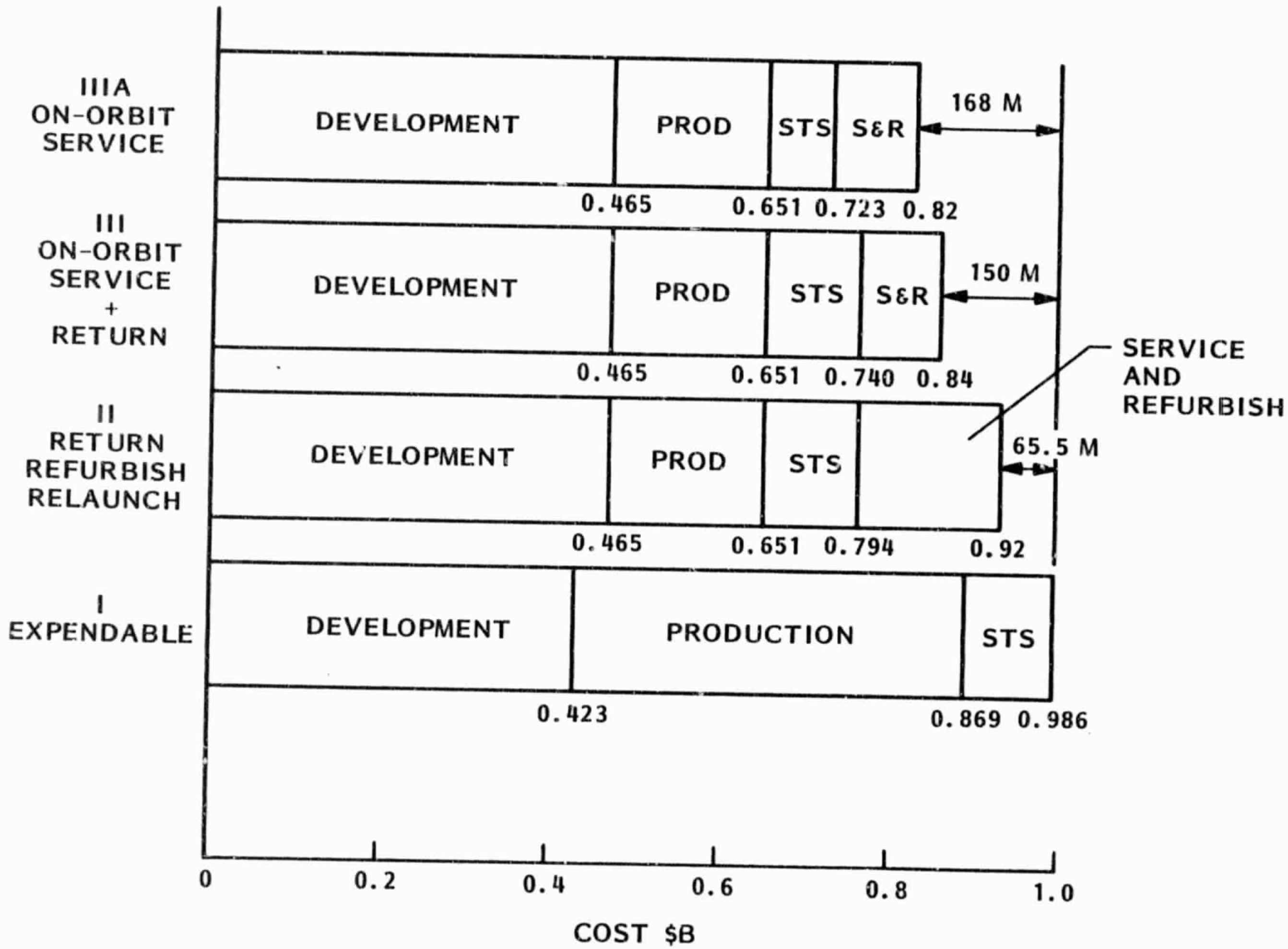
The potential cost avoidance for the Space Telescope options are found from the differences between the gross costs estimated for the expendable case and the three service options. The significant variation between the options are the large production cost for the expendable case and the large refurbishment costs for the ST returned to earth. The differences noted between Case III and IIIA are primarily the additional STS flight for returning the satellite at the end of 15 years in orbit. The detail breakdown of these costs are listed below. See page 23 for mission scenarios.

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
LEO,I	SPACECRAFT			
	DEVELOPMENT	1	372.00	372.00
	PRODUCTION	3	169.09	507.27
	REFURBISHMENT		56.36	.00
	STS USE FEE			
	DEDICATED	3	35.70	107.10
	SHARED	0	18.00	.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE	0	65.00	.00
	REUSABLE-FEE	0	14.00	.00
	REFURBISHMENT	0	40.00	.00
	SERVICE EVENTS	0	.80	.00
	SUPPORT EQUIPMENT	0	.40	.00
	ORBIT REPL. UNIT	0	55.80	.00
	ORU REFURBISH.	0	18.60	.00
	TOTAL			986.37
LEO,II	SPACECRAFT			
	DEVELOPMENT	1	465.00	465.00
	PRODUCTION	1	186.00	186.00
	REFURBISHMENT	2	62.00	124.00
	STS USE FEE			
	DEDICATED	3	35.70	107.10
	SHARED	2	18.00	36.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS	3	.80	2.40
	SUPPORT EQUIPMENT	1	.40	.40
	ORBIT REPL. UNIT		55.80	.00
	ORU REFURBISH.		18.60	.00
	TOTAL			920.90

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
LEO,III	SPACECRAFT			
	DEVELOPMENT	1	465.00	465.00
	PRODUCTION	1	186.00	186.00
	REFURBISHMENT		62.00	.00
	STS USE FEE			
	DEDICATED	1	35.70	35.70
	SHARED	3	18.00	54.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS	3	.80	2.40
	SUPPORT EQUIPMENT	1	.40	.40
	ORBIT REPL. UNIT	1	55.80	55.80
	ORU REFURBISH.	2	18.60	37.20
	TOTAL			836.50
LEO,IIIA	SPACECRAFT			
	DEVELOPMENT	1	465.00	465.00
	PRODUCTION	1	186.00	186.00
	REFURBISHMENT		62.00	.00
	STS USE FEE			
	DEDICATED	1	35.70	35.70
	SHARED	2	18.00	36.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS	3	.80	2.40
	SUPPORT EQUIPMENT	1	.40	.40
	ORBIT REPL. UNIT	1	55.80	55.80
	ORU REFURBISH.	2	18.60	37.20
	TOTAL			818.50

SPACE TELESCOPE COST ESTIMATE

NASA — LOCKHEED



HyPOT OPTIONS COST ESTIMATE

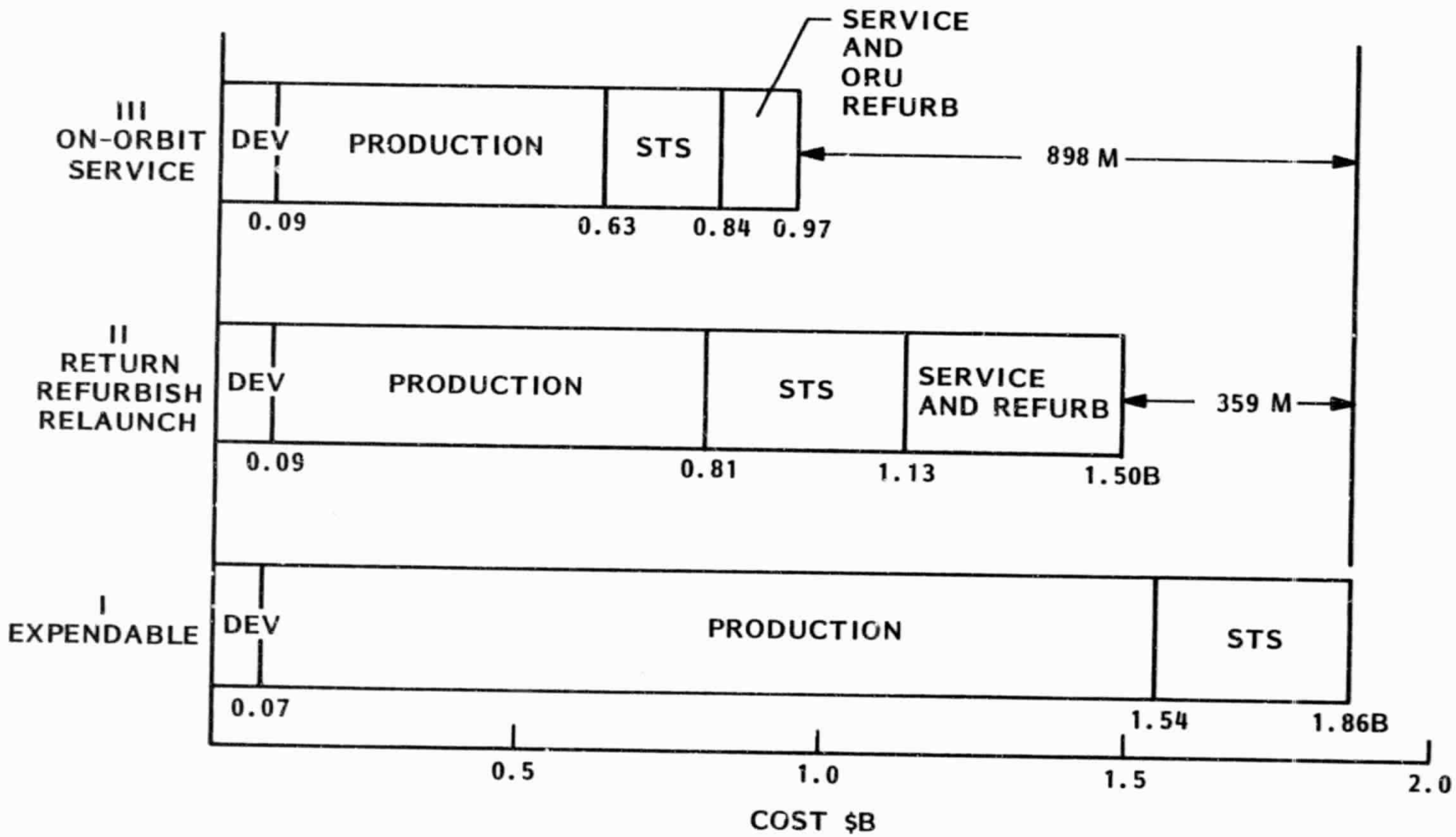
The parametric gross program cost estimate for the three variations of the HyPOT mission are shown in this chart. The potential cost benefits are the differences shown between the baseline expendable case and the serviced cases. The need to substitute three satellites from the operational constellation causes the production quantity for the ground based servicing option to be three more than in the space based servicing option. The significantly larger cost of refurbishing entire spacecraft over that of the ORUs also accounts for the differences in cost estimate. See page 25 for scenarios.

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
HyPOT,I	SPACECRAFT			
	DEVELOPMENT	1	72.00	72.00
	PRODUCTION	27	54.50	1471.50
	REFURBISHMENT		18.17	.00
	STS USE FEE			
	DEDICATED	9	35.70	321.30
	SHARED		18.00	.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS		.80	.00
	SUPPORT EQUIPMENT		.40	.00
	ORBIT REPL. UNIT		20.00	.00
	ORU REFURBISH.		6.67	.00
	TOTAL			1864.80

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
HyPOT,II	SPACECRAFT			
	DEVELOPMENT	1	90.00	90.00
	PRODUCTION	12	60.00	720.00
	REFURBISHMENT	18	20.00	360.00
	STS USE FEE			
	DEDICATED	9	35.70	321.30
	SHARED	0	18.00	.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS	18	.80	14.40
	SUPPORT EQUIPMENT	1	.40	.40
	ORBIT REPL. UNIT		20.00	.00
	ORU REFURBISH.		6.67	.00
	TOTAL			1506.10

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
HyPOT,III	SPACECRAFT			
	DEVELOPMENT	1	90.00	90.00
	PRODUCTION	9	60.00	540.00
	REFURBISHMENT		20.00	.00
	STS USE FEE			
	DEDICATED	3	35.70	107.10
	SHARED	6	18.00	108.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS	18	.80	14.40
	SUPPORT EQUIPMENT	1	.40	.40
	ORBIT REPL. UNIT	3	20.00	60.00
	ORU REFURBISH.	7	6.67	46.67
	TOTAL			966.57

HyPOT OPTIONS COST ESTIMATE



ORIGINAL PAGE IS
OF POOR QUALITY

COMMUNICATIONS PLATFORM COST ESTIMATE

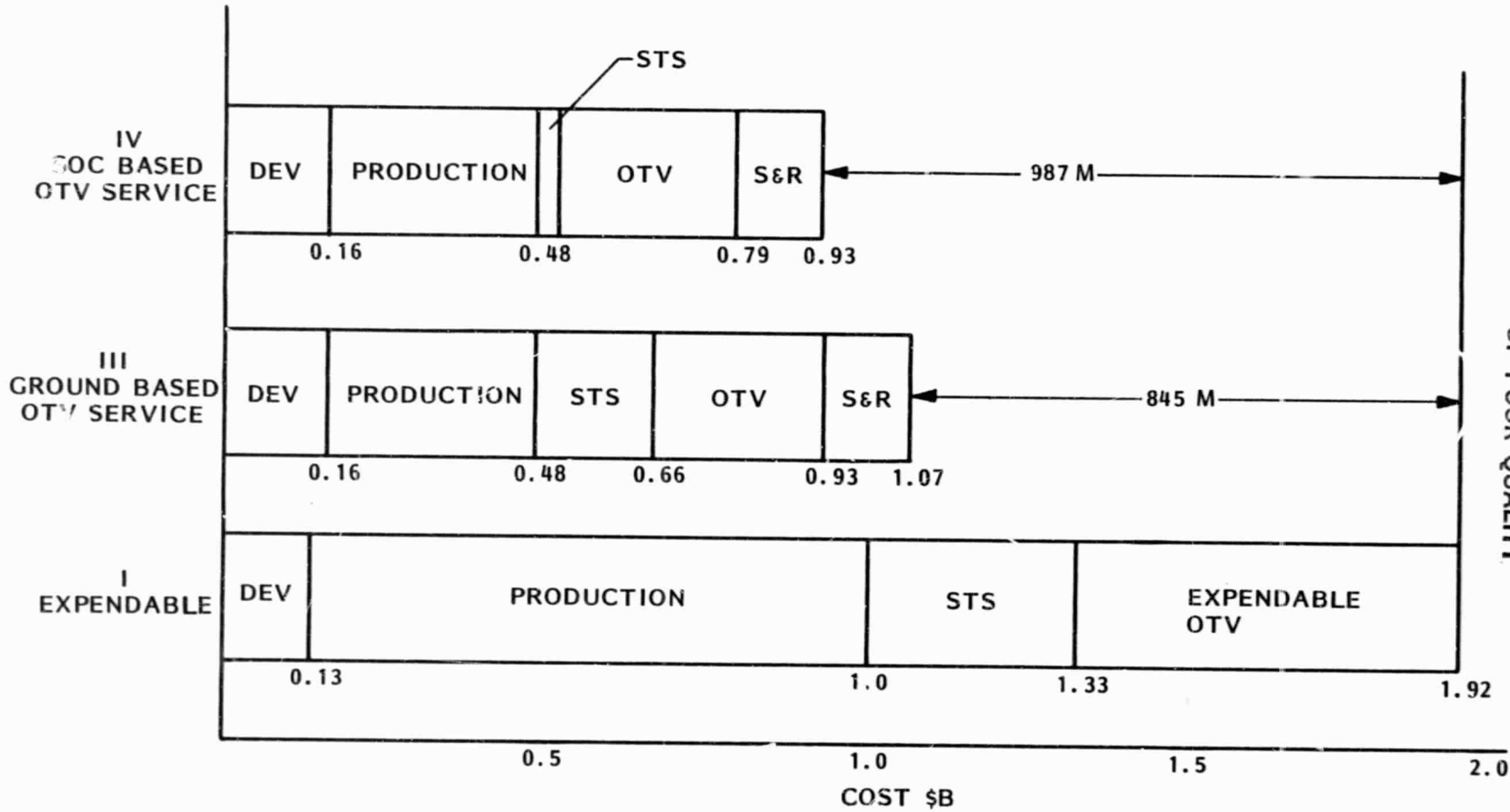
The cost avoidance of the two service options relative to the expendable baseline are shown for the 15 year mission life. In Case I the OTV is assumed to be expendable. In Case III and IV a use fee is charged for the NASA reusable OTV whose development, refurbishment, and refueling costs are assumed sunk. The OTV use charge covers the cost of sustaining operations involved with flying and maintaining the vehicle. The ground rule that the OTV and its expendables are sunk costs was established by JSC. See page 27 for scenarios.

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
GEO, I	SPACECRAFT			
	DEVELOPMENT	1	129.30	129.30
	PRODUCTION	9	97.95	881.59
	REFURBISHMENT		32.65	.00
	STS USE FEE			
	DEDICATED	9	35.70	321.30
	SHARED		18.00	.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE	9	65.00	585.00
	REUSABLE-FEE		14.00	.00
	REFURBISHMENT		40.00	.00
	SERVICE EVENTS		.80	.00
	SUPPORT EQUIPMENT		.40	.00
	ORBIT REPL. UNIT		36.00	.00
	ORU REFURBISH.		12.00	.00
	TOTAL			1917.19

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
GEO, III	SPACECRAFT			
	DEVELOPMENT	1	161.63	161.63
	PRODUCTION	3	107.75	323.25
	REFURBISHMENT		35.92	.00
	STS USE FEE			
	DEDICATED	5	35.70	178.50
	SHARED		18.00	.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE	5	14.00	70.00
	REFURBISHMENT	5	40.00	200.00
	SERVICE EVENTS	9	.80	7.20
	SUPPORT EQUIPMENT		.40	.00
	ORBIT REPL. UNIT	3	36.00	108.00
	ORU REFURBISH.	2	12.00	24.00
	TOTAL			1072.58

PROGRAM	ELEMENT	QTY.	UNIT COST	TOTAL COST
GEO, IV	SPACECRAFT			
	DEVELOPMENT	1	161.63	161.63
	PRODUCTION	3	107.75	323.25
	REFURBISHMENT		35.92	.00
	STS USE FEE			
	DEDICATED	1	35.70	35.70
	SHARED		18.00	.00
	ORBIT TRANSFER VEH.			
	EXPENDABLE		65.00	.00
	REUSABLE-FEE	5	14.00	70.00
	REFURBISHMENT	5	40.00	200.00
	SERVICE EVENTS	9	.80	7.20
	SUPPORT EQUIPMENT		.40	.00
	ORBIT REPL. UNIT	3	36.00	108.00
	ORU REFURBISH.	2	12.00	24.00
	TOTAL			929.78

COMMUNICATIONS PLATFORM COST ESTIMATE



SATELLITE SERVICE SYSTEM ANALYSIS STUDY
ECONOMIC BENEFIT ANALYSIS

- BACKGROUND
- GROUND RULES AND ASSUMPTIONS
- INDIVIDUAL DRM RESULTS
- TOTAL USER BENEFIT PROJECTION

NASA Lockheed

PROJECTED SAVINGS TO USER COMMUNITY

APPROACH

- SEGREGATE MISSION MODEL
  - LOW ALTITUDE, LOW INCLINATION MISSIONS
  - MEDIUM ALTITUDE, HIGH INCLINATION
  - SYNCHRONOUS EQUATORIAL
- POSTULATE AVERAGE MISSION PARAMETERS
  - MISSION LIFE OF 5 YEARS
  - SPACECRAFT MASS OF 2500 kg (5500 LB)
- ASSUME PERCENTAGE DESIGNED FOR SERVICE
  - 30 PERCENT OF LOW AND MEDIUM ALTITUDE MISSIONS
  - 10 PERCENT OF SYNCHRONOUS EQUATORIAL MISSIONS
- APPLY COST AVOIDANCE FACTORS FROM DRM ANALYSIS
  - LOW ALTITUDE/LOW INCLINATION BASED ON SPACE TELESCOPE
  - MEDIUM ALTITUDE/HIGH INCLINATION BASED ON HyPOT
  - SYNCHRONOUS EQUATORIAL BASED ON COMPLAT
- COMULATE COST SAVINGS BY YEAR

COST AVOIDANCE FACTORS

The potential cost avoidance to the three DRMs are shown in the matrix.

The cost avoidance factors are derived from the gross space program potential avoided cost found in the DRM cost analysis. These factors normalize the cost avoidance relative to Case I (expendable spacecraft). They are defined as:

$$\frac{\text{Gross avoided cost}}{\text{Spacecraft weight x program duration}}$$

It is expressed in millions of dolars/1000 lb of spacecraft/operational year.

COST AVOIDANCE FACTORS

- COST AVOIDANCE FACTOR (CAF) IS:

  THE COST AVOIDED RELATIVE TO THE EXPENDABLE SPACECRAFT
  PER THOUSAND POUND SPACECRAFT WEIGHT
  PER YEAR OF SPACECRAFT OPERATION

BASIS	RETURN, REFURBISH RELAUNCH	ON-ORBIT SERVICE	
		STS BASED	SOC BASED
SPACE TELESCOPE			
GROSS ($M)	65.5	168	–
CAF ($M/KLB/YR)	0.19	0.48	–
HyPOT			
GROSS ($M)	359	898	–
CAF ($M/KLB/YR)	0.35	0.89	–
COMPLAT			
GROSS ($M)	–	845	987
CAF ($M/KLB/YR)	–	1.88	2.19

POTENTIAL COST AVOIDED BY THE USER COMMUNITY

A mission model was constructed based on the 1977 NASA mission model modified by the STS Schedule delays and the 1980 Fight Manifest. For years beyond the reach of these references, an extrapolation was made based on expected growth of space utilization. This model was further broken down into four classes:

1. The Low Altitude, Low Inclination Missions
2. Medium Altitude, High Inclination Missions
3. Synchronous Equatorial
4. All others

The fourth class was not used in the cost benefit analysis.

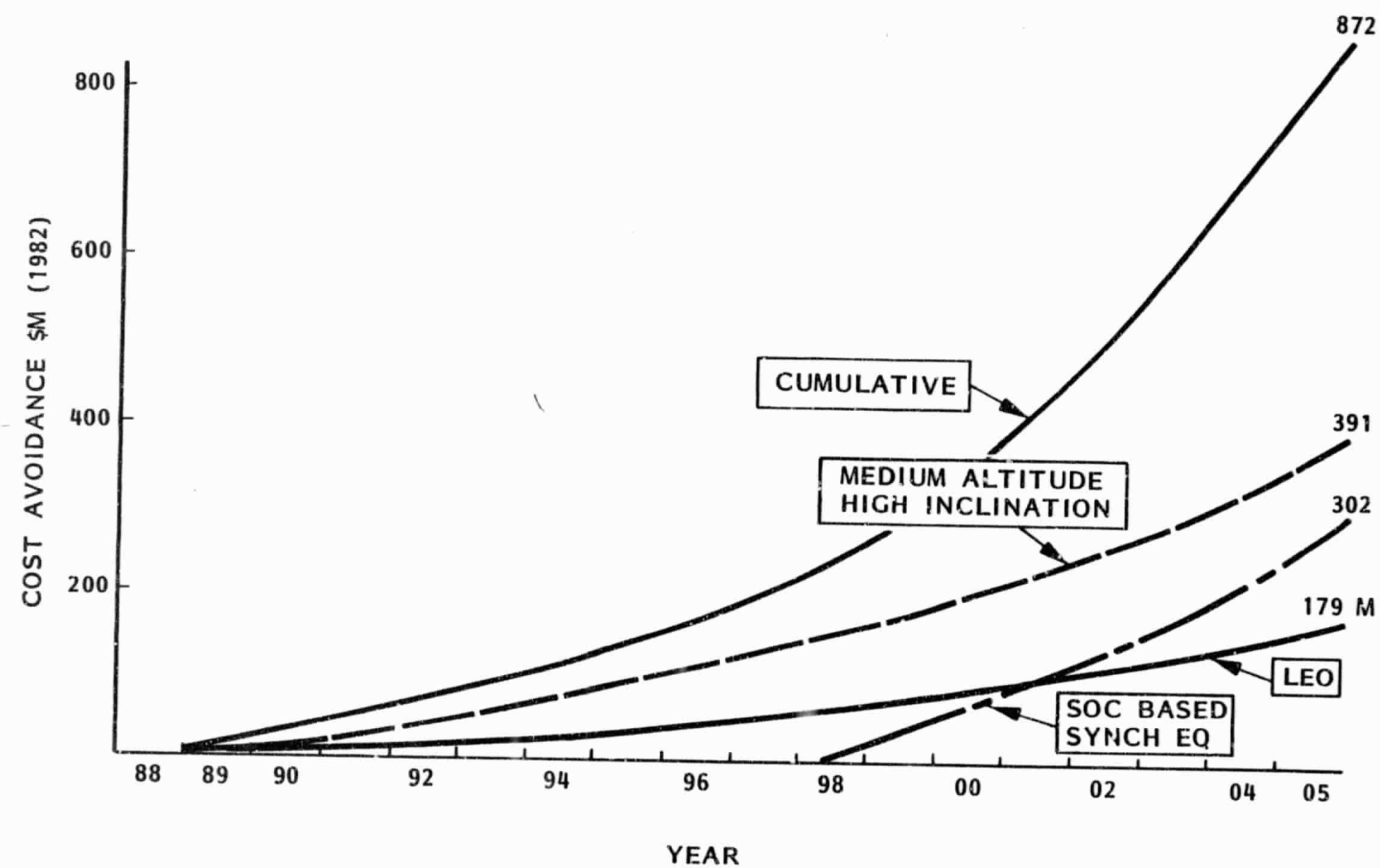
The potential user cost avoidance was computed by multiplying the cost avoidance factor for each class by the assumed average mission duration (5 years) and the average spacecraft weight (5500 lb). This result was then multiplied by the number of missions of that class and the costs avoided were accumulated by year.

After plotting each of the three classes, the cumulative cost avoided by the users of these class of missions were computed.

NASA LOCKHEED

POTENTIAL COST AVOIDED BY THE USER COMMUNITY

CONSTANT YEAR DOLLARS (1982)



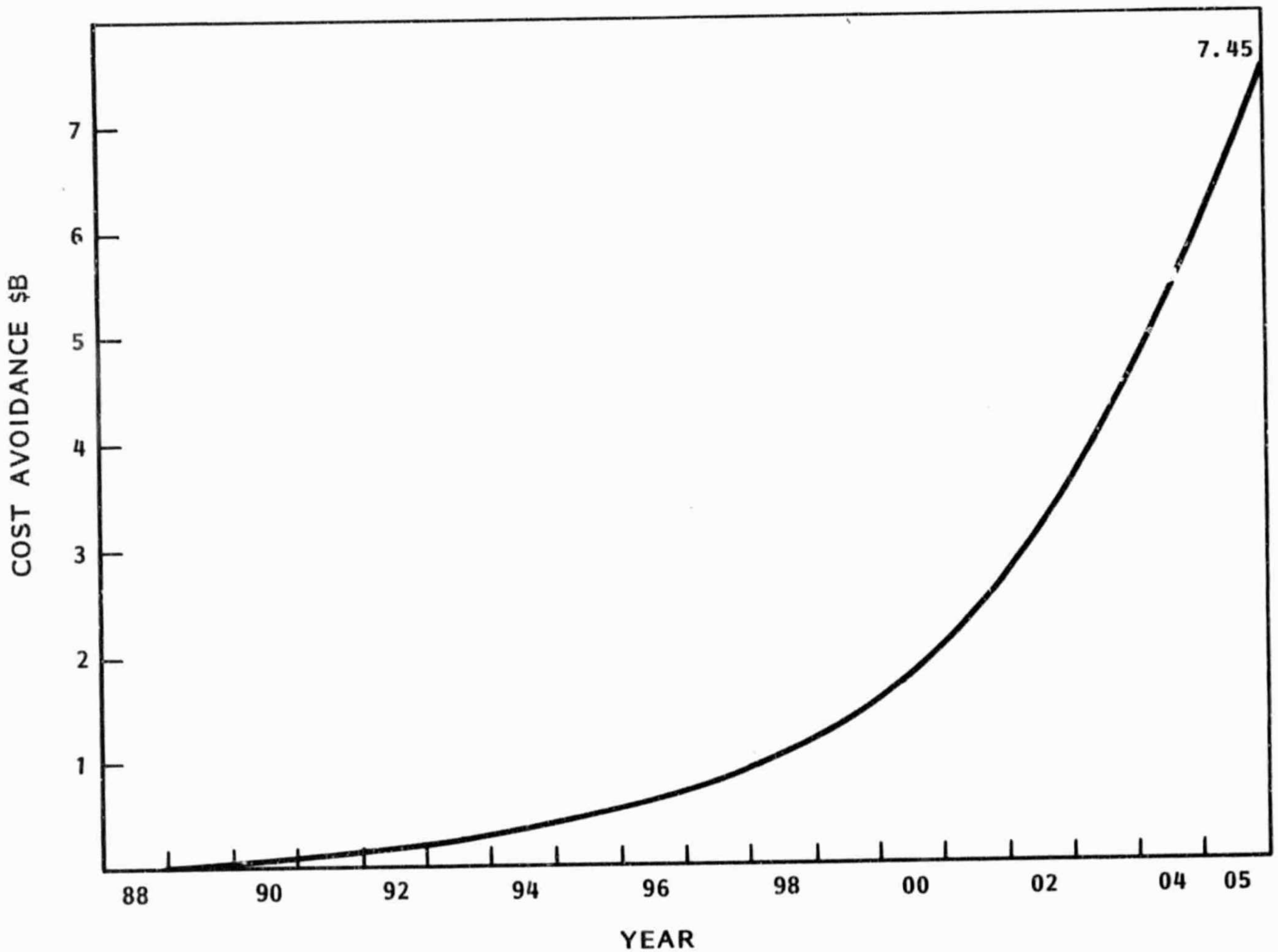
POTENTIAL COST AVOIDANCE
IN THEN YEAR DOLLARS

The cumulated potential cost avoidance from the previous charts was esculated in accordance with the "PRICE" inflation rate schedule. These factors are included below:

R82 = 0.122	R90 = 0.096	R00 = 0.096
R83 = 0.109	R91 = 0.096	R01 = 0.096
R84 = 0.096	R92 = 0.096	R02 = 0.096
R85 = 0.099	R93 = 0.096	R03 = 0.096
R86 = 0.096	R94 = 0.096	R04 = 0.096
R87 = 0.096	R95 = 0.096	R05 = 0.096
R88 = 0.096	R96 = 0.096	
R89 = 0.096	R97 = 0.096	
	R98 = 0.096	
	R99 = 0.096	

POTENTIAL COST AVOIDANCE

THEN YEAR DOLLARS



NASA SSS LOCKHEED

CONCLUSIONS

- SATELLITE SERVICE IS COST EFFECTIVE
  - MAXIMUM BENEFIT ACCRUES FROM ON-ORBIT SERVICE
  - SOC BASING OFFERS GREATER BENEFITS THAN GROUND BASING
- CONSERVATIVE ESTIMATE OF COST AVOIDANCE
  - IN 1982 CONSTANT DOLLARS 872 MILLION
  - IN "THEN YEAR" DOLLARS 7.5 BILLION

PRECEDING PAGE BLANK NOT FILMED

PAGE 42 INTENTIONALLY BLANK

ADVANCED EXTRA VEHICULAR MANEUVERING UNIT STUDY

- REQUIREMENTS

- DESIGN CONSIDERATIONS
  - RADIATION PROTECTION
  - EVA OPERATIONAL PRESSURE
  - MOBILITY EFFECTS
  - TOOL/GLOVE/EFFECTOR
  - ANTHROPOMETRIC DEFINITION
  - EVA LIGHTING
  - EQUIPMENT TURNAROUND

NASA Lockheed

Life Support Systems Inc.

AREAS OF INVESTIGATION:

EVA System Requirements. The Advanced EMU Study will provide a more comprehensive and in-depth analysis of EVA/EMU requirements and design that will enhance operations, lower costs, and increase crew safety for on-orbit satellite servicing.

Design Considerations.

Mobility Effects Task. Space suit joint torque, stability, range, and fidelity to the human analogue, training requirements, EVA time lines, EVA aids, and the level of complexity in these aids was determined. As a part of EMU enhancement, any changes in joint design which would improve the performance of the EVA systems was recommended.

Tool/Glove/Effector Definition Task. The enhancement effects brought about by the integration of power tools and/or effectors to be used with or in lieu of the pressure glove was analyzed. The impact of alternatives on task time lines and cost will be determined.

Radiation Protection Task. The impact of EVA associated with radiation protection was defined.

Equipment Turnarounds Task. An analysis to determine improvements if EVA/EMU equipment is required to optimize turnaround times and costs was performed. Those enhancements that are forseen to accomplish this end objective was assessed and recommended.

EVA Operational Pressure Task. The EVA system operational pressure impacts habitat pressure, EVA time lines, and could impact long-term health of personnel engaged routinely in EVA tasks. Higher suit pressure technology was analyzed and a logical transition from current EVA suit technology to future use systems was recommended.

EVA Lighting Task. The need for adjustable fill-in lighting as an EVA aid and make recommendations for improvements required for satellite service missions was analyzed.

Anthropometric Definition Task. Practical engineering limits relative to sizing the EVA system was defined . The use of sizing elements beyond a "reasonable" limit will have an exponential impact on the system cost. A practical engineering sizing system was recommended.

PURPOSE: TO IMPROVE "PRODUCTIVITY" ASSOCIATED WITH THE EVA TASKS OF SATELLITE SERVICING AND SPACE CONSTRUCTION.

AREAS OF INVESTIGATION:

- o EVA SYSTEMS REQUIREMENTS

- o DESIGN CONSIDERATIONS
  - -- RADIATION PROTECTION
  - -- EVA OPERATIONAL PRESSURE
  - -- MOBILITY EFFECTS
  - -- TOOL/GLOVE/EFFECTOR
  - -- ANTHROPOMETRIC DEFINITION
  - -- EVA LIGHTING
  - -- EQUIPMENT TURNAROUND

The features of the advanced EMU which make it an effective EVA system are:

1. Quick reaction--no pre-breathing is required to transfer from sea level habitat pressures to EVA operations. This requires an EMU operational pressure of approximately 8 psi.

2. Full mobility--the advanced EMU implements a complete mobility system which closely simulates the full nude mobility range of its user. The mobility techniques are passively stable and exhibit extremely low torques to minimize the energy expenditures and assure productive and extended EVA work cycles.

3. Long life components--the construction of large space stations will require extensive numbers of EVA workers who will be on the work site for months at a time. This will require highly reliable and long life components (greater than one million cycles).

4. Extended modularity sizing and maintenance systems--by designing the improved EMU as a series of standard components which are "length" sized to fit individual workers by quick connect components, "shift" assembly of EMU components to fit workers on alternate 8-hour shifts will significantly reduce the in-orbit inventory of suit components and the attendent volume required for storage. The improved EMU will make EVA so efficient that the most effective way to handle many in-orbit satellite launches and recoveries will be through the use of EVA rather than fully automated systems.

GUIDELINES

"THE OPTIMIZED EVA SYSTEM IS CONSIDERED FOR THE YEAR 2000 OPERATIONAL REQUIREMENTS."

"LOGICAL TRANSITION FROM THE CURRENT EMU TO THE OPTIMUM (CIRCA 2000) SYSTEM WILL BE DEFINED."

RESULTS

THE OPTIMUM EVA SYSTEM WILL MEET THE FOLLOWING REQUIREMENTS:

- NO PRE-BREATH AND MIXED O_2/N_2 EMU ENVIRONMENT
- FULL MOBILITY
- IN-ORBIT MINIMUM SERVICING
- EXTENDED MODULARITY TO ENHANCE SERVICING AND LOGISTICS
- USEFUL IN-ORBIT LIFE PER OPERATIONAL CYCLE IS ; 1M
- RADIATION PROTECTION (UP TO 300 NM @ 60° INCLINATION)

REQUIREMENTS

The current state of advanced pressure suit technology is such that all major mobility characteristics of the human body can be implemented in a space suit without compromise to suit reliability or safety. Since the most difficult tasks the EVA worker faces will be those which are unplanned and of an emergency nature, the Requirements document aims at minimizing the reduction in the human body's capability.

Key factors to maximizing EVA performance is the provision of adequate foot restraint at the work-site, full mobility of the EMU, adequate visibility, and effective hand/tool interface between worker and the satellite.

ADVANCED EMU REQUIREMENTS

GENERAL

TASKS--EVA CONSTRUCTION, DEPLOYMENT, STOWAGE, OPERATION, MAINTNEANCE, AND REPAIR
PERSONNEL--EVA-TRAINED ONLY
SORTIE--WORK CYCLE 6 HOURS CONTINUOUS EVA; SINGLE OR MULTIPLE SHIFT
--NO PRE-BREATHING
RESTRAINT--FOOT AND/OR TORSO
--TETHERED EQUIPMENT
EVA TRANSLATION--HAND RAILS, HAND HOLDS, CRANE, PERSONAL PROPULSION SYSTEM, FOOT RAILS
STOWAGE--IN HABITAT
LIGHTING--AREA AND EMU INTEGRAL

RELIABILITY LIFE REQUIREMENTS

-- 10 6-MONTH MISSIONS = 10 OPERATIONAL CYCLES (OC)
-- 1 OC = 154 6-HOUR SORTIES = 924 HOURS
-- SUIT JOINT DESIGN CYCLE RATE = 6 CYCLES/MIN.
-- 1 OC LIFE REQ = 924 HOURS (60 MIN/HR) 6 C/M = 332,640 CYCLES
-- 25% CONTINGENCY = 83,160 CYCLES
-- TOTAL OPERATIONAL PRESSURE REQ = 415,800 CYCLES
-- BENCH TEST 2 X 10C = 831,600
-- 40 MIN. VENT PRESS/SORTIE
-- 154(40)6 = 36,960 VENT CYCLES/OC
-- 25% CONTINGENCY = 9,240 CYCLES
-- TOTAL VENT CYCLES = 46,200 CYCLES
-- BENCH TEST 2 X 10C = 92,400 CYCLES
-- TOTAL LIFE CYCLE FOR 10 O'CX2 = 9,240,000 CYCLES

ADVANCED EMY REQUIREMENTS (CONT'D)

FAIL SAFE DESIGN--30 MIN. CONTINGENCY PLSS

- -- LATCHES

o MAINTAINABILITY

- -- ALL COMPONENTS MEET 10% GROUND REPLACEMENT (EXCEPT GLOVES)
- -- SPARES AT THE COMPONENT LEVEL
- -- EASE OF POST-SORTIE BREAKDOWN INSPECTION AND BUILD-UP

o SAFETY

- -- PROTECTION FROM SHARP EDGES, ABRASION SURFACES
- -- SAFETY FACTORS--DESIGN = 2(PLUG LOAD (PL) + MAN-INDUCED LOAD (MIL))
  --BURST = 3(PL + MIL)

o PERFORMANCE

- -- FULL MOBILITY
- -- LOW TORQUE

ASSUMPTIONS, CONSTRAINTS, AND DEFINITIONS

The orbits selected for analysis were 220 X 220 NMIX $28\frac{1}{2}^{\circ}$ inclination and 300 X 300 nmi X 60° inclination.

For the purposes of this analysis, only exposure to radiation from the natural van Allen Belts was estimated. Injection of energetic protons from solar flares or energetic electrons from exoatmospheric nuclear bursts was not considered.

Exposure due to cosmic rays is insignificant for the six-month mission duration.

The standard spacecraft wall thickness of 0.1 in. (0.254 cm.) of aluminum was found sufficient to attenuate the radiation for the specified orbital missions to a level low enough that exposure within the spacecraft can be neglected. <u>This would not be true for higher orbits</u>.

The relative biological effectiveness (RBE) of various radiations is defined to be the empirical ratio of the dose delivered to tissue divided by the dose in X-rays or γ rays that would produce the same biological effect. The dose in rem is obtained by the relationship

$$\text{dose (rem)} = \text{RBE} \times \text{dose (rads)}$$

The value of RBE depends upon the particle energy. It is normally obtained by comparing radiation doses required to produce 50% fatalities in small animals thirty days after irradiation.

When tissue is exposed to radiation with a range of particle energies, the RBE is calculated as an average. For tissue exposed behind a shield of varying thickness, the RBE will be a function of shield thickness.

The RBE for electrons is unity.

Analysis

Calculations of doses within spherical and plane slab aluminum shields were provided by J. C. Lee of LMSC. The calculations were for 24 hours of exposure in the specified orbits; current NASA models were used for the van Allen Belt radiation. The results indicate that the particle spectra are similar in the two orbits. However, the average electron flux is 33 times greater in the higher orbit, and the proton flux 2.5 times greater.

ADVANCED EMU RADIATION PROTECTION

- VAN ALLEN BELT RADIATION USED FOR ANALYSIS
  - SOLAR FLARES AND EXOATMOSPHERIC NUCLEAR BLASTS NOT CONSIDERED
  - COSMIC RAY INSIGNIFICANT
- CONCLUSION:
  - NORMAL EVA SYSTEM DENSITIES SUFFICIENT FOR LEO RADIATION PROTECTION
  - NOT TRUE FOR GEO

ASSUMPTIONS, CONSTRAINTS, AND DEFINITIONS (cont'd)

The curves provided by Lee were modified as follows: First, the constant proton RBE of 10 employed by Lee was replaced by depth-dependent RBE factors estimated as described below. Second, the spherical shield results provided for the higher orbit were scaled to plane-slab curves using ratios obtained from the two sets of curves supplied by Lee for the lower orbit. (Plane-slab dose curves were found to be more appropriate due to the dominance of near-surface doses.)

The RBE factors used to estimate proton doses were estimated with $\propto$ varying from a value of 4.5 near the surface to 1.8 at greater depth.

The curves provided by Lee were extrapolated to 0.1 g/cm^2 with constant slope. A comparison with results of Hamilton Standard (Exhibit I) was made possible by estimating their EMU fabric areal density at 0.1 g/cm^2. Their calculated skin exposure of 0.7 rem/24 hrs at 400 km circular x $28\frac{1}{2}^{\circ}$ inclination is in satisfactory agreement with Lee's result for the plane-slab calculation. This result was extrapolated to the 300 X 300 nmi X 60° orbit conditions in two ways. A linear extrapolation of their results for a 55° inclination orbit to 555 km (300 nmi) produced a skin exposure estimate of 20.0 rem/24 hrs. A second method of extrapolation made use of the observation that the skin dose is almost entirely due to electrons. Multiplying the Hamilton Standard result of 0.7 rem/24 hrs by the ratio of electron fluxes (33X), produced an estimate of 23.1 rem/24 hrs for skin exposure at 300 nmi. These estimates are all in satisfactory agreement.

The symbol ⊕ shows the 24-hour accumulated dose in organs protected only by the surrounding tissue. Estimates of the effects of shielding can be made by moving these points to the right a distance (in inches Al) equivalent to the shielding (in g/cm^2) being considered.

Conclusions

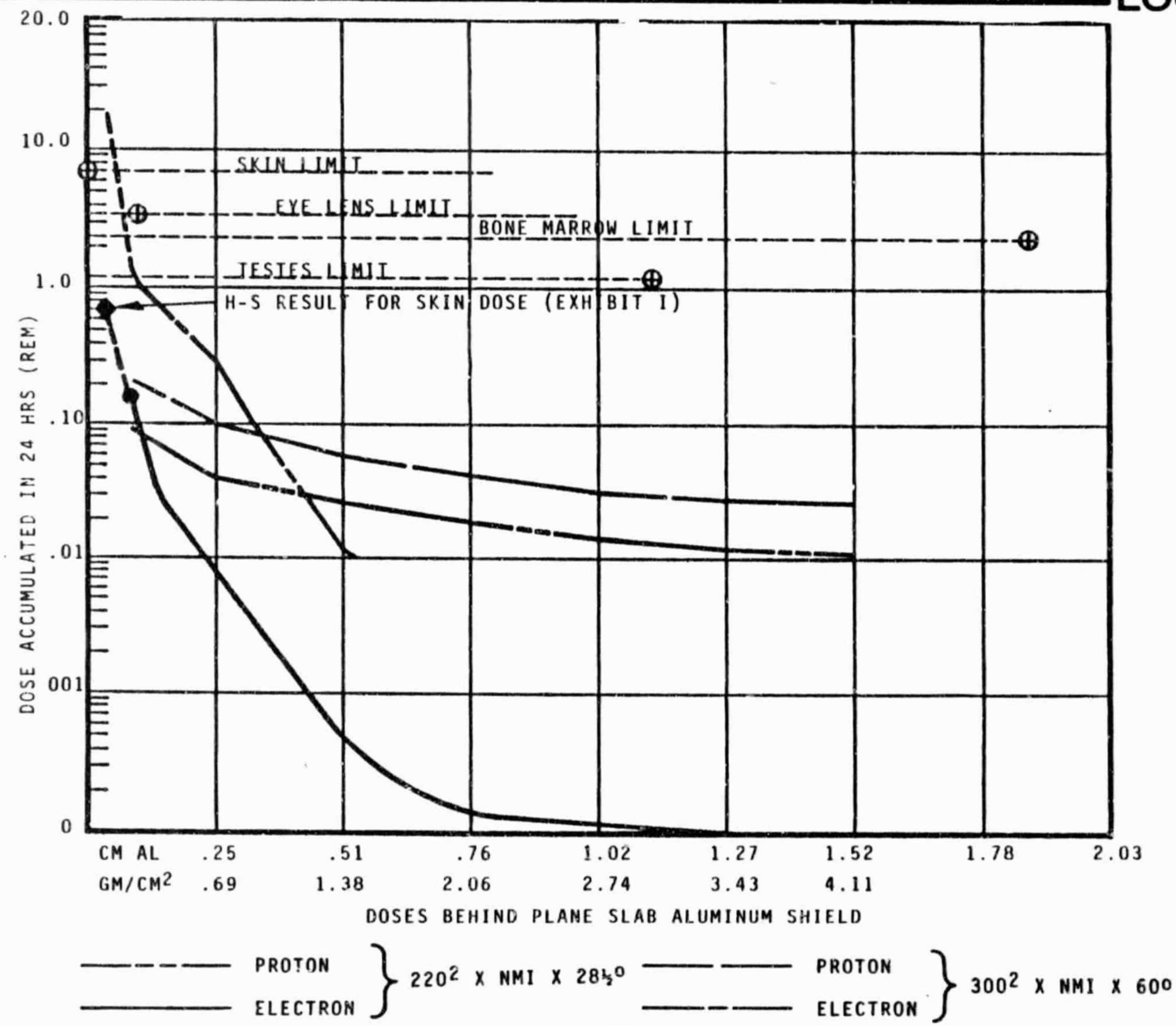
At the relatively low orbits considered, little shielding is required. For this reason electrons, causing higher doses near an exposed surface than protons, are dominant. (If heavier shielding were required, as it would be higher within the van Allen Belts, the more penetrating protons would be the dominant factor in determining mission limits.)

Exhibits G and H show that skin exposure is the determining factor.

For the lower orbit, 0.1 g/cm^2 of protection is adequate.

For the 300 X 300 nmi X 60° orbit, the extrapolated results indicate that 0.2 g/cm^2 would be adequate.

ADVANCED EMU RADIATION PROTECTION (CONT'D)



OPERATIONAL PRESSURE CONSIDERATIONS:

The first consideration in selecting EVA system operational pressure is to establish the requirement that the system provide for "quick reaction," i.e., no pre-breathing. The pre-breathing requirement poses a severe constraint on EVA because:

- the space worker's utility is reduced
- special logistics for pre-breathing are required
- the risk of "bends" increases
- immediate EVA becomes hazardous in contingency/emergency situations
- reduced effectiveness of the "buddy" rescue system

With the elimination of pre-breathing, suit pressure and habitat pressure become interrelated by

$$P_{suit} = \frac{PPN_2 \text{ habitat}}{1.5}$$

where $PPN_{2\ habitat}$ is the partial pressure of nitrogen in the habitat and P_{suit} is the EVA system operational pressure. Two options then become available:

1. habitat pressure of 14.7 psia; suit pressure of 8.0 psia
2. habitat pressure $<$ 14.7 psia; suit pressure correspondingly reduced according to above relationship

Those factors favoring Option 1 are:

- reduced cabin cooling fan power
- reduced flammability hazard
- improved cooling of cabin avionics
- reduced oxygen toxicity hazard potential
- no impact on pressure sensitive biological/physiological and materials processing experiments
- no impact on present configuration of the Shuttle Orbiter

ADVANCED EMU OPERATIONAL PRESSURE

- RECOMMEND--SEA LEVEL PRESSURE IN HABITAT (14.7 PSIA)
  - 8 PSIA SUIT PRESSURE WITH 50% N_2 - 50% O_2 MIX
- NO PRE-BREATHE OF O_2 REQUIRED
- LONG-TERM EXPOSURE TO HIGH O_2 CONCENTRATIONS UNDESIRABLE
- HABITAT PRESSURE AFFECTS
  - COOLING POWER REQUIREMENTS
  - AVIONICS RELIABILITY
  - FLAMMABILITY HAZARDS
  - O_2 TOXICITY
  - BIOLOGICAL/PHYSIOLOGICAL AND MATERIAL PROCESS EXPERIMENTS

Those factors favoring Option 2 are:

- reduced nitrogen tankage and gas resupply for habitat
- reduced EVA system leakage, power and emergency system size
- minimum impact on Shuttle EMU design

There are, however, overriding considerations which necessitate at least an EVA system with 8 psia capability. First, little is known about long term physiological effects of prolonged exposures to high concentrations of oxygen. There are indications that excess oxygen over a long term produces tissue irritation and blood changes.

Second, reduced habitat pressures may in the future prove unacceptabel due to incompatibility with pressure sensitive life science and materials processing experiments.

Third, a less than 8 psia suit pressure would be incompatible with the proposed international rescue vehicle with its 14.7 psiz cabin. It is therefore recommended that an 8 psia operational pressure with 3.0 psi PPO_2 be established as a design requirement for the EVA pressure enclosure. This will then allow for a sea level habitat pressure.

ADVANCED EMU OPERATIONAL PRESSURE (CONT'D)

- 8 PSI TECHNOLOGY IS AVAILABLE
- ON-GOING PROGRAM TO DEMONSTRATE ADVANCED EMU FEASIBILITY
- POTENTIAL FOR NEAR-TERM IMPLEMENTATION

MOBILITY EFFECTS

The mobility capabilities of an EVA pressure enclosure affect training requirements, EVA time lines, EVA aids, and the level of complexity of these aids. The current Shuttle EMU has limited lower body mobility. Also, the two bearing-single axis flat pattern shoulder joint requires programmed movements. The result of these factors are an extensive training requirement on the use of the EMU, a lengthening of EVA time lines due to the inefficiencies associated with programmed movements, and an increased complexity of EVA aids to accommodate the limited mobility.

Suit technology developed since 1963 has provided high mobility, low torque joints which would enable personnel to essentially duplicate tasks in a shirt sleeve environment. This technology, developed through several generations of advanced suit concepts, has a proven record of high reliability, long life, and the capability of operating at higher operational pressures than the current Shuttle EMU.

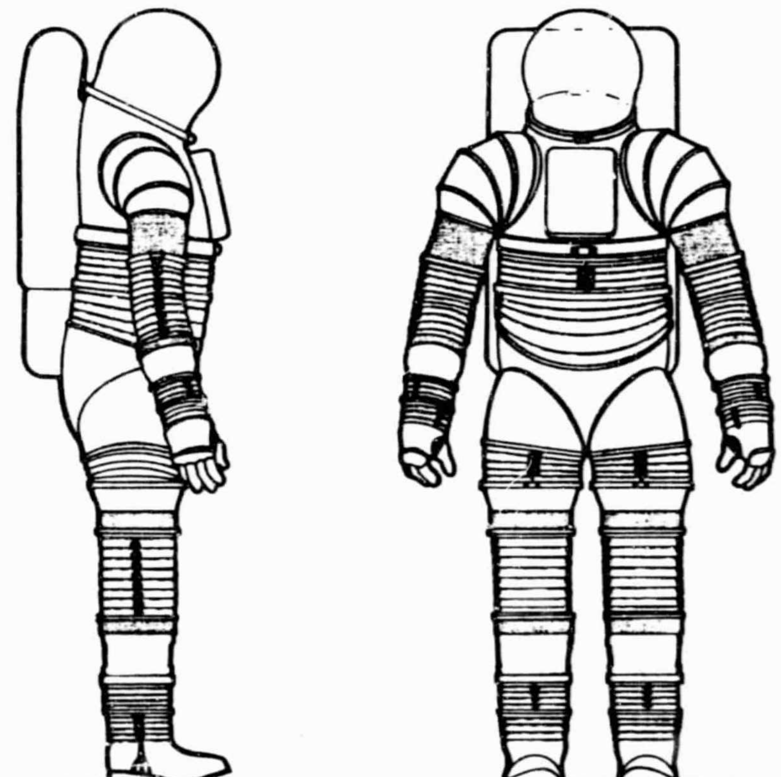
ADVANCED EMU MOBILITY EFFECTS

o THE ADVANCED EMU WILL IMPLEMENT NON-PROGRAMMED FLEXIBLE JOINTS AS FOLLOWS:

-- SHOULDER	3-AXIS
-- ELBOW	SINGLE-AXIS
-- WRIST	3-AXIS
-- WAIST	2-AXIS
-- HIP	3-AXIS
-- KNEE	SINGLE-AXIS
-- ANKLE	2-AXIS

o FULL MOBILITY FAVORABLE AFFECTS

- -- TRAINING TIME
- -- EVA AID COMPLEXITY
- -- TASK TIME LINES



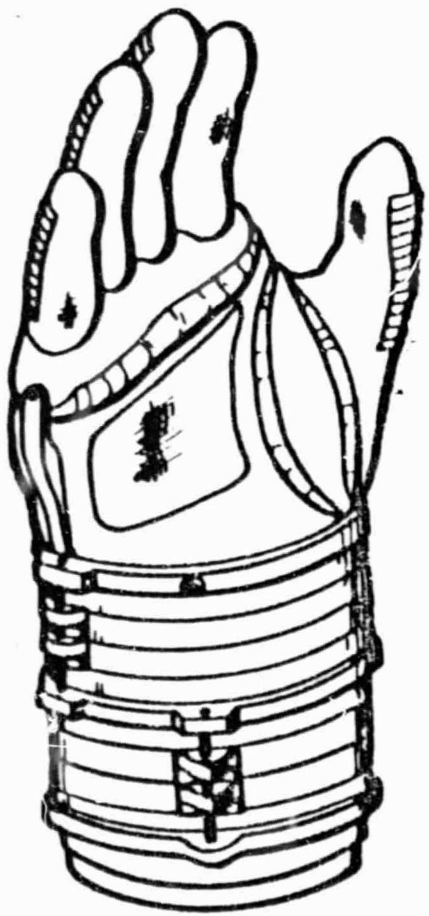
THE GLOVE

The glove is the key to an effective EMU. Historically, it is the least successful of space suit components.

Thumb-finger opposition with first metacarpal, low torque stable joint implementation at palm and thumb is key to efficient "effector" use of hand. No glove to date has fully accomplished above implementation.

Additional attributes to glove performance are:

- o Full range low torque finger flexion
- o Good fit with good tactile transfer through glove to sensitive hand/finger areas
- o Minimal layering and layer "slip" of tactile areas
- o Large palm area with good fit to hand for gripping of manual and powered tools



- FOR ORBITS CONSIDERED, RADIATION IS NOT A SERIOUS PROBLEM
  - -- GLOVE USED FOR LEO
  - -- FUTURE GEO WILL REQUIRE INCREASED HAND PROTECTION/EFFECTOR SYSTEM
- GLOVE REQUIRES
  - -- 1ST METACARPAL JOINT IMPLEMENTATION
  - -- GOOD TOOL "GRIP INTERFACE"
  - -- THUMB-FINGER OPPOSITION
  - -- IN-ORBIT REPLACEMENT OF GLOVE ELEMENT TO WRIST

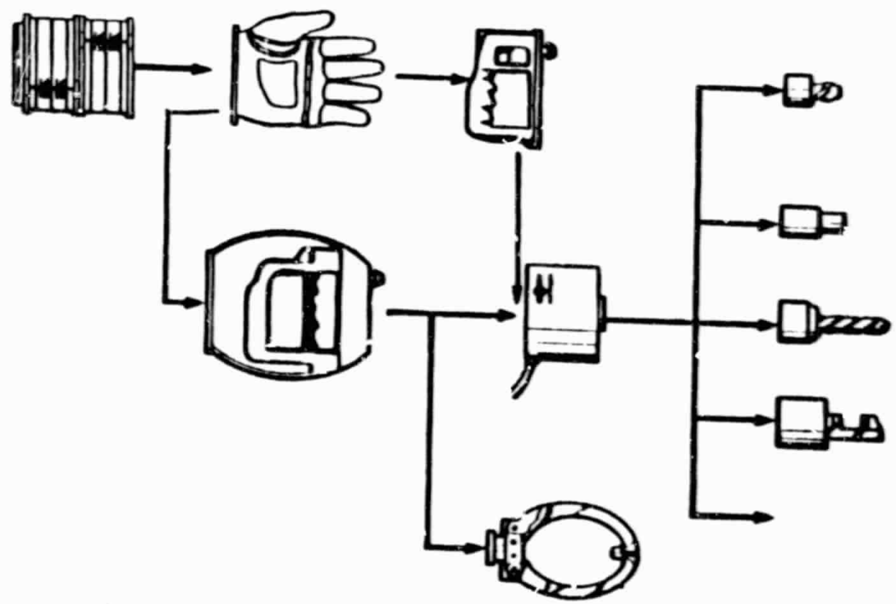
TOOL/GLOVE/EFFECTOR

The tool/glove/effector (TGE) is a series of interrelated elements which, when integrated into the extravehicular suit assembly, represents a means of overcoming some shortcomings inherent in EVA gloves. By design, the current NASA EVA pressure glove does not meet the desirable requirements associated with the projected harsh EVA workplace environment specified for the year 2000. Studies have shown that in-orbit construction at higher altitudes may require greater glove durability and radiation protection. In an effort to reinforce current gloves to meet these future EVA needs, complications arise in the design of hand tools due to the additional glove bulk. The TE, therefore, offers an attractive alternative to glove reinforcement. Modular in composition, the TGE consists of an adapter handle that is either portable or integral with the suit. Affixed to the handle would be a gripper or power component. Tools, in turn, would be snapped onto the power component. This concept promises to reduce hand fatigue that would occur with bulky glove reinforcement and increase portection of suit pressure integrity by eliminating the need for intimate contact between crewmember's pressure glove and potentially hazardous work pieces.

o NEED FOR MULTI-PURPOSE POWER ELEMENT FOR

-- VARIABLE TORQUE MULTI-ROTATION
-- RECIPROCAL MOVEMENT

o INTERFACE TO GLOVE OR TO RADIATION PROTECTIVE "CAN"



A NOVEL APPROACH TO EVA LIGHTING:

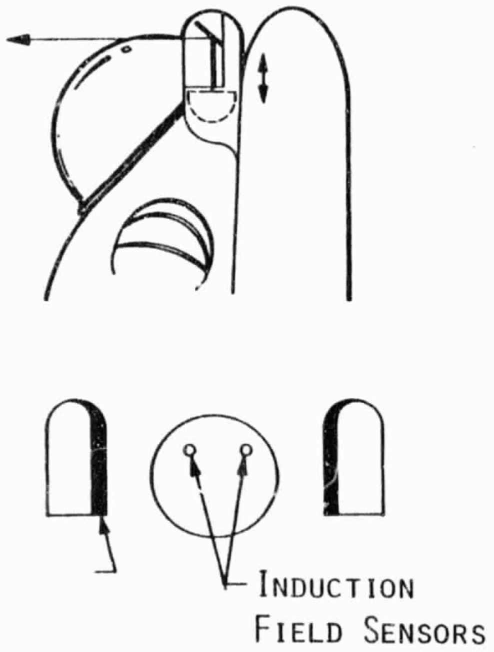
Recognizing the need for fill-in lighting that is adjustable both in intensity and position, LSSI proposes a pack-mounted system utilizing current state of the art helmet-mounted sighting devices to command light positioning. This system, as proposed, would automatically vary beam direction and light intensity by sensing head movement and light intensity of the work area. This regenerable system would be compatible with both ship power source, for pre-EVA checkout, and with separate self-maneuvering unit power for personnel rescue and transfer operations.

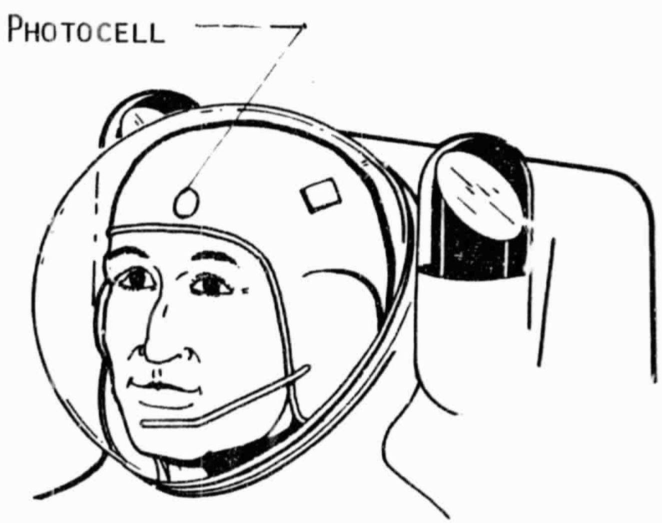
To establish beam direction, sensors would be worn on a bump hat to establish head position relative to the helmet via an induction field (see Figure 5b). In order to reduce the mass of moving elements, thereby making the system more responsive to head movement, servoed mirrors direct the light from the lamps which are vertically fixed to the rigid backpack. Light intensity is established by a photocell mounted to the forehead portion of the bump hat. Located inside the helmet, it will be able to compensate for the anticipated 20% visible transmittance loss through the liquid crystal visor.

Compact yet effective, this lighting system not only frees the crewmember's hands to perform EVA tasks, but also grants him the needed liberty to move form one location to the next free of concern of his lighting requirements. This system, being integral with the man and his needs, offers a valuable aid to all extravehicular activities.

o SUPPLEMENTAL FILL-IN LIGHTING REQUIRED
  -- ORBITAL DARK SIDE-LIGHT SIDE OPERATIONS

o LIGHT INTENSITY AND POSITION AUTOMATIC CONTROL SYSTEM RECOMMENDED





EVA SYSTEM ANTHROPOMETRICS

Early space suits were designed as derivations of emergency pressure flight suits. Such suits were never intended for use while pressurized except under emergency conditions for short periods of time. The demand for mobility while pressurized grew with the advent of Extravehicular Activity (EVA) and lunar exploration.

A group of developmental space suits which began with the JSC-Litton hard space suits approached the problem of pressurized mobility from a new direction. Those suits were conceived and designed as articulated anthropomorphic structures instead of as specialized articles of clothing. Such an articulated structure is constructed of an assembly of specially formed elements connected to flexible joint elements.

It was apparent that the only way such an assembly could be sized to a range of subject sizes was to provide different sized elements that could be assembled in combination to fit an individual.

This sizing approach was explored in the JSC-Litton RX-3 program and in the JSC-AiResearch AES program. In both cases, the concept was to provide suit element cross sections that would accommodate the largest individual and vary the length of the element for fit.

The sizing matrix presented here offers a fit to a wider range of subject sizes by varying both cross sections and lengths of selected elements.

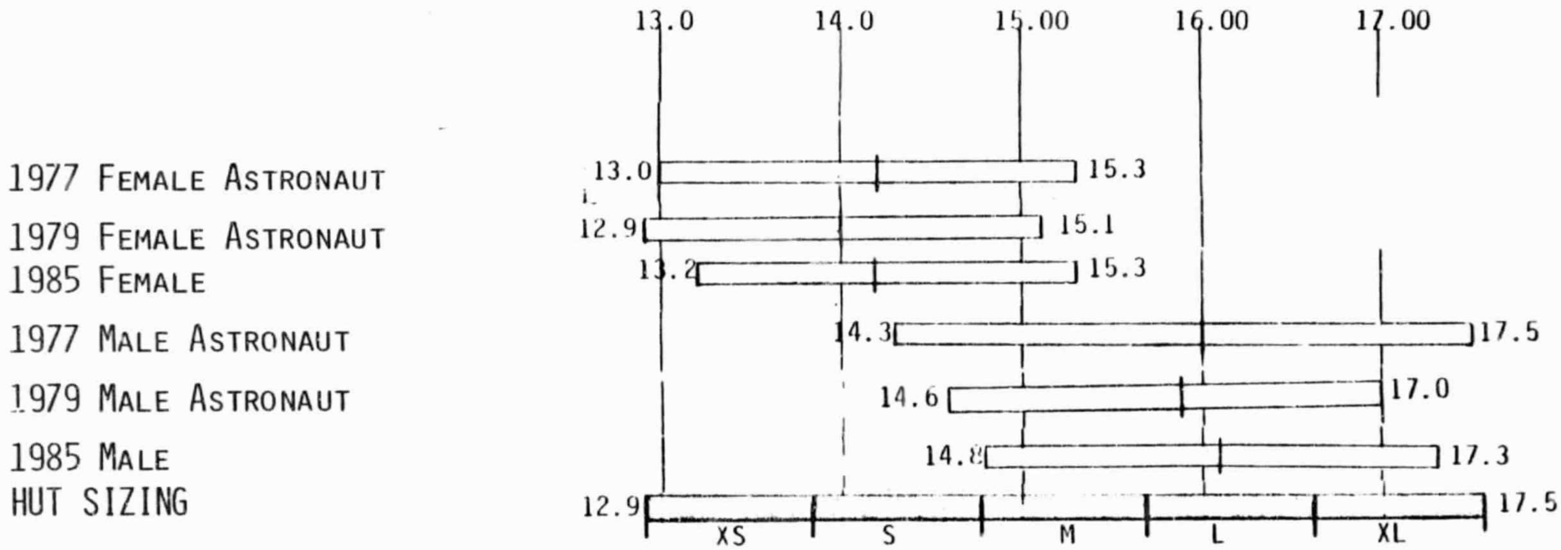
Anthropometric data from several sources has been utilized to define the sizes for each pressure garment element. The 5th to 95th percentile range of each group was selected as the range that should be covered by the modular sizing matrix.

SIZING CONSIDERATIONS

Definition of a rational modular sizing system is based on selected anthropometric measurement for each modular element. Data from several sources has been extracted to define the ranges needed in each sized element. It should be noted that because of inconsistencies in the types of measurements taken in different surveys, not all measurements required for this sizing study were available. In most cases, the missing data has been projected by simple regression equations based on stature.

- o BI-MODAL DISTRIBUTION OF MALE AND FEMALE POPLATION COMPLICATES MODULAR SIZING SYSTEM
  - -- FEASIBLE MODULAR SIZING SYSTEM PROPOSED
  - -- TWO RANGES OF CIRCUMFERENTIAL SIZING COMPONENTS
  - -- INTERMEDIATE LENGTH INSERTS
- o MORE STRINGENT SELECTION OF ASTRONAUT COULD SIGNIFICANTLY AFFECT SYSTEM COSTS

SIZING CRITERION: BIACROMIAL BREADTH

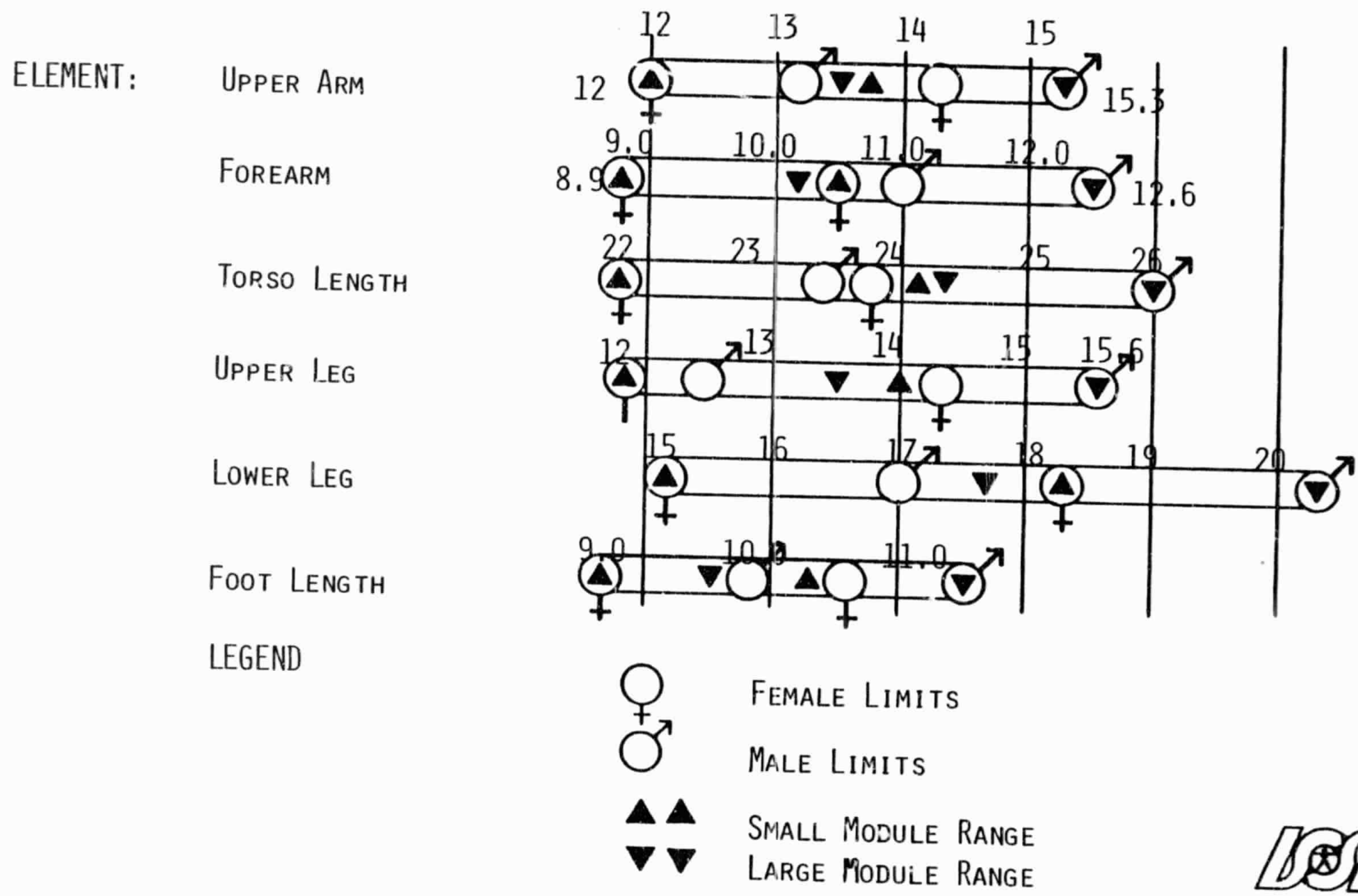


NASA Reference Publication 1024 provides projections for measurements of 1985 males based on population growth curves. Similar data is provided as 1985 female measurements. However, due to lack of data on growth curves of the female Air Force population, the information provided is an estimate based on the officer sub-series from Anthropometry of Air Force Women by Clauser, et. al.

Since it seems reasonable to assume that the female population will undergo the same rate of growth as the male, we have prepared projections for the 1985 female based on the 1968 Air Force data and assuming the same growth rate in weight and stature as that projected for men. Other measurements for 1985 females were then derived by multiple regression equations.

Data derived from male Air Force flight personnel are skewed by preselection due to screening during earlier selections. The data on Air Force women while also skewed by preselection is probably less so since it does not represent flight personnel only.

As the selection of workers for long term construction and maintenance tasks in orbit takes place, it is possible that both male and female candidates will cover a wider range of measurements than the current data allows. The sizing matrix can be enlarged or shifted for certain measurements, but there will be limits to the sizes of subjects that it is possible to fit. Once the sizing matrix is established it may be necessary to select EVA worker candidates who fit within the measurements defined. The production and inventory costs of fitting a nonconforming subject would be extremely high.


ELEMENT:
UPPER ARM
12
13
14
15
12
15.3
FOREARM
9.0
10.0
11.0
12.0
8.9
12.6
TORSO LENGTH
22
23
24
25
26
UPPER LEG
12
13
14
15
15.6
LOWER LEG
15
16
17
18
19
20
FOOT LENGTH
9.0
10.0
11.0
LEGEND
FEMALE LIMITS
MALE LIMITS
SMALL MODULE RANGE
LARGE MODULE RANGE

EVA tasks, both planned and contingent, would be greatly enhanced by the suggested EMU. Modular yet reliable, and having a design goal of ten operational cycles, this unit would provide a means of mobile protection for several crewmembers on rotating shifts.

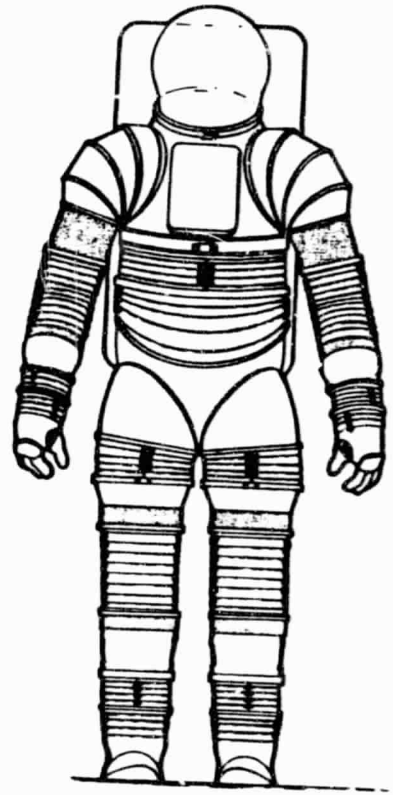
Two of the proposed EMUs would service four crewmembers working sequential six-hour shifts. Upon completion of their six-hour sortie, the first team would return to the ship, go through any required decontamination procedures, and doff the unit. The EMU would quickly and easily break down for cleaning and/or resizing. Each element of the EMU would have an identifier so that a computer log could be kept on component use rather than total suit life. The total sortie time and task would be logged in for the unit being worn. The computer would then automatically record wear values for each element of the total EMU. This would allow extended life items to be used to their fullest capacity. Additional front and back identification would be provided for those segments of the suit that are constructed in a toroidal joint configuration. After each sortie, these joints would be rotated 180° so that the front would then become the back and vice versa, thus maximizing their useful life. Using the computer log system, any wear trends which might develop would be quickly discovered and brought to the attention of the design department for corrective action. It is envisioned that a complete resizing, donning, and donned check-out could be per-foremd within a period of forty minutes. With man-induced loads associated with occupancy of the EMU, a pressure slightly higher than normal test pressure should be used prior to EVA.

The high reliability built into the EMU limits the amount of required in-orbit maintenance. Outside of normal freshening of the garment, maintenance tasks consist of lubricating bearings and sealing gaskets, visual inspection, and some limited testing.

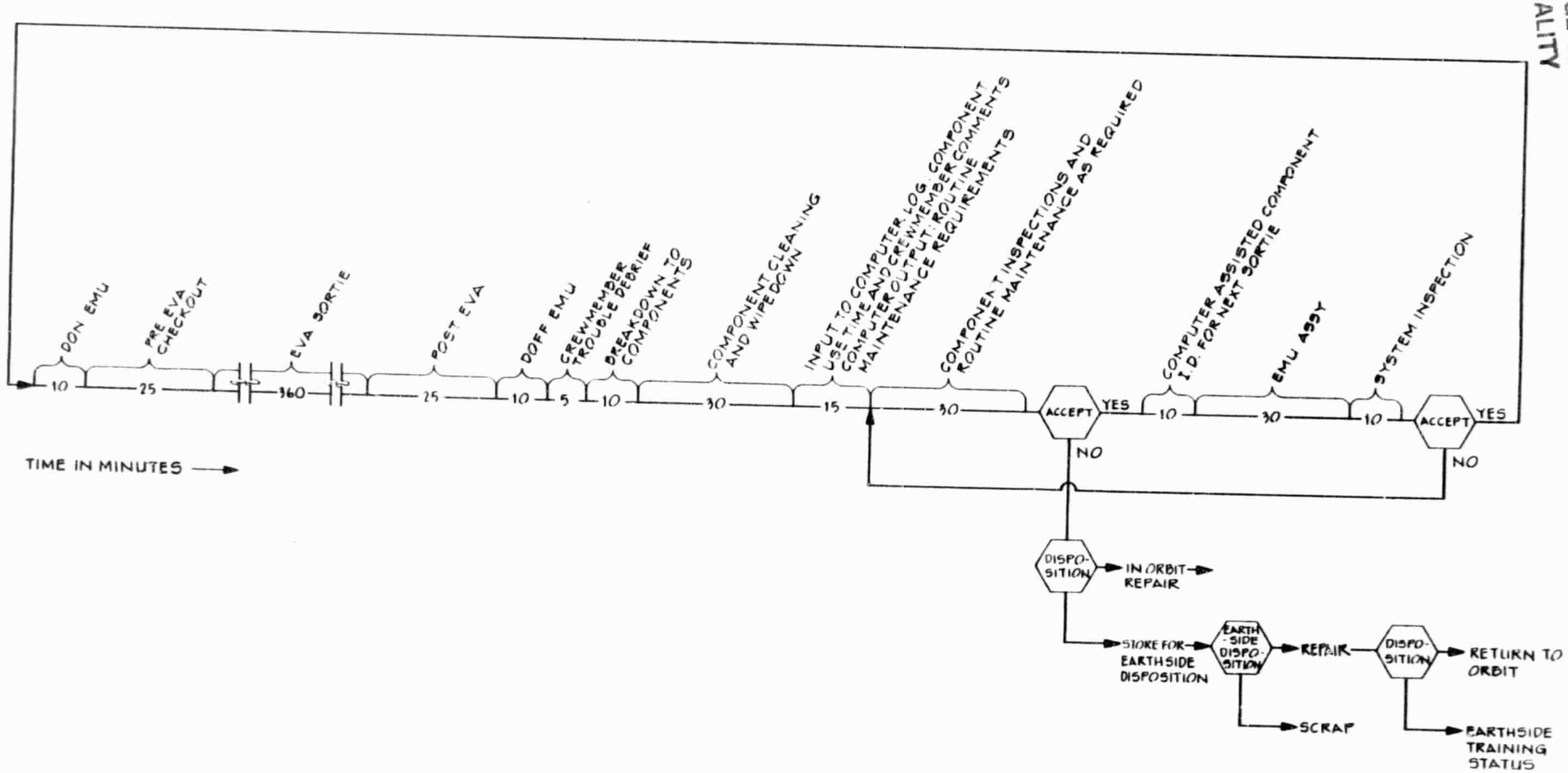
More extensive testing performed on a periodic (six-month) basis would be handled by maintenance crews stationed on earth. Bearings and bearing races would be torn down, cleaned, soft goods replaced, reassembled, and evaluated. X-ray examination of hardware and rigid structures would be one means of determining their relative repair status. Upon evaluation, the element would either be returned to service in orbit, or retained on earth for training purposes. All elements not meeting the evaluation criteria would be scrapped.

ADVANCED EMU EQUIPMENT TURNAROUND

- o EXTENDED MODULARITY LONG LIFE COMPONENTS YIELD
  - -- MINIMUM NUMBER OF EMU COMPONENTS IN ORBIT
  - -- EASE OF COMPONENT INSPECTION/REPLACEMENT
- o COMPUTER AIDED IN-ORBIT COMPONENT MAINTENANCE AND EMU ASSIGNMENT
  - -- EARTH MAINTENANCE AND ASSIGNMENT OF COMPONENTS
  - -- FAILURE/TROUBLE STATISTICS AND FLAGGING OF MARGINAL ELEMENTS



ORIGINAL PAGE IS OF POOR QUALITY


DON EMU
PRE EVA CHECKOUT
EVA SORTIE
POST EVA
DOFF EMU
CREWMEMBER TROUBLE DEBRIEF
BREAKDOWN TO COMPONENTS
COMPONENT CLEANING AND WIPEDOWN
INPUT TO COMPUTER LOG: COMPONENT USE TIME AND CREWMEMBER COMMENTS COMPUTER OUTPUT: ROUTINE MAINTENANCE REQUIREMENTS
COMPONENT INSPECTIONS AND ROUTINE MAINTENANCE AS REQUIRED
COMPUTER ASSISTED COMPONENT I.D. FOR NEXT SORTIE
EMU ASSY
SYSTEM INSPECTION
10
25
360
25
10
5
10
30
15
30
10
30
10
ACCEPT
YES
NO
ACCEPT
YES
NO
TIME IN MINUTES
DISPO-SITION
IN ORBIT REPAIR
STORE FOR EARTHSIDE DISPOSITION
EARTH-SIDE DISPO-SITION
REPAIR
SCRAP
DISPO-SITION
RETURN TO ORBIT
EARTHSIDE TRAINING STATUS

COMPONENT	ANTICIPATED NOMINAL LIFE	DISPOSITION AFTER NOMINAL LIFE
TOROIDAL JOINTS THIGH, KNEE, ANKLE, TORSO, ELBOW, WRIST, WAIST	3 M's	REPAIR AND USE FOR TRAINING OR DISASSEMBLE, SALVAGE HARDWARE FOR REUSE, SCRAP SOFT GOODS
BEARING JOINTS HIP, SHOULDER, WRIST	10 M's	REFURBISH AND USE FOR TRAINING OR SCRAP IF DAMAGED
HARD ELEMENTS TRANSITION ELEMENTS, HUT, SIZING ELEMENTS	10 M's	USE FOR TRAINING OR SCRAP
GLOVE *	1/10 M	REPAIR AND USE FOR TRAINING OR DISASSEMBLE, SALVAGE HARDWARE FOR REUSE, SCRAP SOFT GOODS

* GLOVES QUICKLY REMOVABLE FROM 3 M WRIST ASSEMBLY

ADVANCED EMU SUMMARY

o ADVANCED EMU UTILIZES AVAILABLE TECHNOLOGY
- -- RADIATION--MINIMUM IMPACT ON DESIGN FOR LEO
  - --GEO NOT ADDRESSED
- -- OPERATIONAL PRESSURE--≈8 PSI MIXED GAS
- -- MOBILITY EFFECTS--FULL MOBILITY, LOW TORQUE
- -- TOOL/GLOVE/EFFECTOR--MODULAR GLOVE FOR LEO
  - --EFFECTOR PRESSURE VESSEL FOR GEO
  - --MODULAR POWER TOOL INTERFACE
- -- ANTHROPOMETRICS--BI-MODAL EXTENDED MODULARITY SYSTEM
- -- EVA LIGHTING--SERVOED INTENSITY AND ARTICULATION FOR FILL-IN LIGHTING
- -- EQUIPMENT TURNAROUND--MODULAR COMPONENT BUILD UP IN ORBIT
  - --COMPUTER AIDED TRACKING AND TROUBLE IDENTIFICATION

PRECEDING PAGE BLANK NOT FILMED

PAGE 78 INTENTIONALLY BLANK